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by Paul S. Bogart

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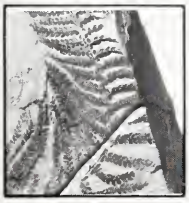

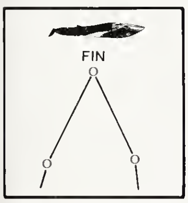

concerns

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This unusual map shows the Earth as a flat ellipse, and shows Antarctica in relation to the other continents and world's oceans. (After H. G. R. King, 1969, The Antarctic*)*

A Reader's Guide to the Antarctic

by James H. W. Hain

Antarctica is the least known of the seven continents on Earth. It is high, cold, and dry; with less precipitation than one might think. Antarctica is an island continent—and opposite from the Arctic in more ways than one. Whereas the Arctic at the North Pole is an ocean surrounded by land, Antarctica is land surrounded by ocean. However, it is a land mass that is concealed; 99 percent of the continent is buried under perpetual ice up to 4½ kilometers thick. If the ice were removed, a smaller, rocky land mass of some 7 million square kilometers (2.7 million square miles) would be revealed (see map on page 21).

With its icecap, Antarctica is roughly circular in shape—broken only by the lengthy Antarctic Peninsula, some 800 miles from base to tip, which points finger-like toward distant South America, and by the two great extensions of the Southern Ocean—the Ross and Weddell seas. The nearest mainland to Antarctica is the southern tip of South America, some 600 miles from the Antarctic Peninsula—but separated from it by the Drake Passage, one of the world's stormiest stretches of ocean.

With a diameter of about 4,500 kilometers (2,800 miles), and an area of 14 million square kilometers (5.4 million square miles), it is the fifth largest continent—larger than the United States, but less than half the size of Africa.

Highest and Coldest

Antarctica is the highest continent; its average height is three times that of other continents. At 4,900 meters, Vinson Massif is the highest mountain. The mountains that span the continent, the Transantarctic Mountains, are one of the world's longest mountain chains (see map on page 33). This chain divides the continent into two geologically contrasting parts—Lesser Antarctica and Greater Antarctica. The smaller of the two, Lesser Antarctica, would consist of a group of islands if the ice were not present.

Temperature and light are major environmental factors—in the extreme. Antarctica is the coldest continent, with minimum temperatures considerably lower than the Arctic. In the vicinity of the South Pole, the average annual temperature is minus 49 degrees Celsius, and the coldest temperature ever recorded on Earth has been recorded in Antarctica (see page 92). The fierce winds characteristic of the area push the already harsh temperatures down. For nearly 6 months a year, the Sun does not rise above the horizon.

Despite the overwhelming abundance of ice and snow, precipitation is slight. At the South Pole, situated on a high plateau 3,000 meters (10,000 feet) above sea level, rain never falls, and less than 2 inches of snow is measured annually.

Ice

Because of the cold, the modest precipitation rarely melts. Therefore, it accumulates, and more than 90 perent of all the ice and snow in the world is locked up in Antarctica. This ice sheet is virtually one huge glacier of continental proportions—comparable only with the one that covers much of Greenland. The great ice sheet that covers the continent gradually creeps outward and spills onto the surrounding sea—to the extent that Antarctica is fringed by vast floating ice shelves. These ice shelves are distinctive features of Antarctica—and they are sizable. The Ross Ice Shelf, for example, covers an area larger than France. From these shelves, massive tabular icebergs break off (see page 41), and drift northward. While the ice shelves are largely freshwater ice, saltwater ice, or pack ice is also a feature of the surrounding Southern Ocean. This frozen sea surrounding the continent varies in area from about 2.7 million square kilometers (1 million square miles) in southern summer to more than 18 million square kilometers (7 million square miles) in winter.

The influence of Antarctica and its surrounding ocean on climate is substantial. The barren, ice-clad island of South Georgia lies in latitude 54 degrees South—2,000 miles from the South Pole. In the corresponding latitudes of the Northern Hemisphere are population centers like Liverpool and Belfast.

There are no permanent inhabitants in Antarctica. What little exposed rock there is supports only sparse vegetation (mostly algae, lichens, and mosses), and, apart from microbial life (bacteria and fungi), just a few hardy insects. While a great variety of insects, birds, and land mammals live in the high Arctic year round, only a handful of tiny invertebrates, and not a single land vertebrate, can survive the Antarctic winter.

In contrast to the paucity of life on land, there is a richness of life in the sea; for it is in the ocean that the region's abundant life is found. Seabirds, seals, and whales are perhaps the best known animals—consuming vast quantities of fish, squid, and krill.

An Oceanic Boundary

What is considered the boundary of the Antarctic? While the Antarctic continent is almost entirely contained within the Antarctic Circle, at 66 degrees 33 minutes South latitude, the generally accepted boundary is an oceanic one. The Antarctic Convergence—a belt of water some 20 to 30 miles

wide girdling the Southern Ocean, roughly located around 50 degrees South latitude—marks a change in oceanic currents, water properties, and biological characteristics (see map on page 23). Therefore, the region north of the Antarctic Convergence is referred to as the subantarctic, and that to the south, the Antarctic. The Antarctic region includes the continent, the southern part of the Southern Ocean, and several islands—among them the South Shetland Islands, the South Orkney Islands, and South Georgia.

The Antarctic Treaty System (ATS)

The International Geophysical Year (IGY), 1 July 1957 to 31 December 1958, was a cooperative endeavor by world scientists to improve their understanding of the Earth and its environment. Much of the field activity took place in the Antarctic, where 12 nations established some 60 research stations. The scale of the IGY focused national and international planning, funding, and organization in a way never before seen. As the end of the IGY approached, many of the involved nations sought continued Antarctic activity.

Proposals for continuing activity were reviewed through the Special (now Scientific) Committee on Antarctic Research—an international nongovernmental body formed in 1957, and clearly the most suitable body to coordinate post-IGY programs. In May 1958, the United States proposed a treaty that would set aside the continent for scientific use only.

It took several meetings to establish a common basis of agreement. Then, a formal treaty conference was held in Washington, D.C., beginning on 15 October 1959. On 1 December, the Antarctic Treaty was signed. The 12 IGY countries were the drafters of the treaty, and its original signatories. The treaty was ratified, and entered into force on 23 June 1961.

Consultative and Non-consultative Parties

The continuing operation of the treaty is enacted by means of Antarctic Treaty Consultative Meetings (ATCMs), held on a biennial basis. Each meeting has generated recommendations regarding operation of the treaty, that, when ratified by participating governments, become binding on them. (The ratification of international law often involves the enactment of corresponding domestic law. For example, the Agreed Measures for the Conservation of Antarctic Fauna and Flora was ratified by the United States as Public Law 95-541, the Antarctic Conservation Act of 1978.)

The "consultative" parties, or those with voting rights at these meetings, originally were the 12 Antarctic Treaty Consultative Parties (ATCPs). Since that time, eight additional nations have achieved consultative status (see page 14). Another 18 nations have acceded to the treaty, and thereby agree to abide by the treaty, but because they do not conduct substantial scientific research in the Antarctic, they attend meetings as observers, in a non voting status. To date, 38 nations have signed the treaty, representing more than 80 percent of the world's population.

Claimants and Non-claimants

Among the complicating elements in Antarctic policy is the issue of claims and sovereignty. Britain made the first claim in 1908. In 1923, a portion of this claim was awarded to New Zealand. Australia staked a claim in 1933, and Norway and France made subsequent claims. In the 1940s, Argentina and Chile made claims that not only overlapped each other, but also overlapped the 1908 British claim (refer to map on page 23). Of the seven "claimant" nations, only Australia, Britain, France, Norway, and New Zealand reciprocally recognize their respective claims.

Aside from these claimant nations are those who are active in the Antarctic, but who have staked no claim, do not recognize the claims of others, and maintain a "general interest" in the area. Among these non-claimant nations, the United States and the Soviet Union, while making no claims, have reserved the right to do so, and have argued that they have strong historical grounds for claims.

Science and Politics

Science is usually held to be the reason for the Antarctic Treaty—a treaty that establishes a "continent for science." Indeed, early on, the 12 IGY nations saw scientific cooperation as a long-term key to the Antarctic political dilemma. Science, however, plays several roles in the Antarctic.

A principal role of science is in establishing qualification for achieving consultative, or voting, status to the Antarctic Treaty System for countries that were not original signatories. Article IX of the treaty states that during such time as [a]. . . "Contracting Party demonstrates its interest in the Antarctic by conducting substantial scientific research activity there, such as the establishment of a scientific station or the dispatch of a scientific expedition". . . it enjoys consultative status.

There also is the matter of "presence." Under international law, the key criterion for determining territorial sovereignty, or the basis for any legal claim, is effective occupation—demonstrated through permanent settlement. In the Antarctic, the scientific stations come closest to meeting this condition. Claimants typically site their stations in their claimed areas. The United States, which has occupied the geographic South Pole continuously since November 1956, thus has one of its stations situated not only directly at the South Pole, but also at the hub of every claim. The Soviet Union, on the other hand, has ringed the continent with its stations.

Antarctica was formerly a region for explorers, whalers, and scientists. Now, lawyers, managers, fishermen, commercial interests, and even tourists are turning their attention toward the South Pole. This issue of *Oceanus*, then, addresses several of the timely and fascinating aspects of the history, science, and policy of this remote seventh continent, and its surrounding ocean.

James H. W. Hain is Assistant Editor of Oceanus, *published by the Woods Hole Oceanographic Institution.*

Introduction:

The Challenge of Antarctic Science

by David J. Drewry

For four decades, Antarctica—that south polar fastness almost twice the size of Australia and which so captured the imagination of early explorers—has been considered "a continent for science." Its remoteness, hostile environment, and unusual political status maintained through the Antarctic Treaty has held it in a delicate time warp in which scientific endeavor (aimed at establishing a basic knowledge of the continent and the surrounding seas) has been its pre-eminent activity.

Since the late 1970s, however, the tempo of international interest in Antarctica has accelerated, spurred by the prospects of the region's potential for future economic development, a desire by some to ensure total environmental protection for the continent in the face of such threats, and a wish by some nations to involve themselves in the intriguing juridical details of the treaty system, which comes up for possible review in 1991. This volume of *Oceanus*, which examines the contemporary issues facing Antarctica, is, therefore, both timely and informative.

The Rise of Science

The remarkable circumnavigation of Antarctica in 1775 by Captain James Cook, and his reports of the abundant wildlife of the peri-Antarctic Islands, principally of seals, did not go unnoticed in Europe and North America, and drew in commercial enterprise with great swiftness. By 1820, however, the fur seal industry on South Georgia (the principal concentration of activity) was in decline—the indiscriminate and rapacious harvesting could not be sustained, and sealers sought new breeding grounds, and, in this manner, actively extended geographical exploration to the South Shetland and South Orkney Islands, and to the Antarctic Peninsula. This uneasy symbiosis of exploration and exploitation of the early 19th Century was not repeated, for by the latter part of the century, when commercial attentions turned to the oil products of elephant seals and, more importantly (from 1904), to whales, the scientific investigation of Antarctica, encouraged by the learned societies of several nations, emerged as an independent and influential undertaking. The Sixth International Geographical Congress of 1895 identified Antarctica as a target for new investigations, and led directly to 20 years of intense exploration that saw the names of de Gerlache, Nordenskjöld, Drygalski, and Scott indelibly printed on the face of the Antarctic, marking the beginning of "The Heroic Age" of geographic and scientific exploration.

The diminuendo in widespread interest between the two World Wars reflected concern with domestic and economic issues. Interest re-emerged during and immediately after World War II, and led to the major involvement of 12 nations during the International Geophysical Year (1957/58). In the decade that followed, much of the reconnaissance knowledge that we possess of the continent and its surrounding seas was established. Science emerged as a significant policy issue in providing the acceptable presence for interested nations in Antarctica. Indeed, the Antarctic Treaty of 1959 (page 11), in establishing the region solely for peaceful purposes, underscored the crucial role of scientific investigation on a free and collaborative basis. Under Article IX (2), the accession of a country to the treaty as a contracting party is by demonstrating " . . . its interest in Antarctica by conducting substantial scientific research activity there, such as the establishment of a scientific station or the dispatch of a scientific expedition."

Challenges to Antarctic Science

Science in Antarctica is now at a threshold. Behind are the solid contributions of 40 to 50 years of undisputed, basic research; ahead lies a period of increased politicization and economic aspirations woven through with legal, environmental, and conservation issues. These issues have resulted from the marked increase in the number and diversity of nations with interests in Antarctica (eastern and western bloc, developed and developing countries).

Economic and Commercial Enterprise

A third epoch of exploitation of Antarctica, following the sealing and whaling periods, has now begun—with forays by fishing vessels from several nations to assess the viability of Antarctic waters for the harvesting of krill, fin fish, and squid. The promise of new and major protein sources,

considered possibly equivalent to the present annual world marine catch (70 to 80 million metric tons), has attracted the attention of many countries new to Antarctica. Their concern is not simply in terms of direct exploitation by their fleets, but also through consideration of the international principles that should be applied to the utilization, management, and conservation of these marine resources.

At an early stage in the fishing for krill, which occupies a crucial, central, but still not fully understood niche in the food web of the Southern Ocean, the Antarctic Treaty powers* assessed the manner in which the disastrous fisheries experiences of the past could be avoided. The result was the 1980 Convention for the Conservation of Antarctic Marine Living Resources (CCAMLR). This convention seeks to maintain a balance throughout the whole Southern Ocean ecosystem by managing the various components, rather than focusing on stocks of a species attractive for harvesting.

For Antarctic science in general, and marine biological research in particular, the message from increased interest in economic factors is clear. Within the limits of most national Antarctic program budgets, policy decisions will have to be made as to the relative level of support provided to underpinning the strategic science needs of CCAMLR under Article XV. The pressures from national and international environmental lobbies (for example, Greenpeace) on those countries that have embraced CCAMLR may mean that such redirection of financial and logistic resources for science is likely to occur sooner rather than later. This state of affairs need not be viewed with alarm by the more academically oriented members of the marine community, since there is a convergence of scientific aims in understanding the details of the Southern Ocean stemming explicitly from the ecosystem approach to management. Indeed the scientific community has responded to these imperatives—the SCAR-SCOR BIOMASS** program (see article page 75) stands as an important start to coordinated, targeted research. It is the redeployment of resources from other areas of science into marine research that will be of concern, as well as the more esoteric view that such "directed" science may be considered another constraint on the strongly perceived, but ill-defined, freedoms of intellectual pursuit.

Economic Studies

Turning to the issue of economic minerals, the challenges to Antarctic science are more opaque, but are based on the same premise that national concerns over the likely abundance of hard-rock and hydrocarbon wealth in the Antarctic may lead to the redistribution of the science dollar, pound, and yen (see also page 32). Already programs to investigate the economic geology of regions of Antarctica have begun. The Soviet Union, for instance, has had such expeditions to the inner regions of the Ronne and Filchner Ice Shelves, and Chilean, Argentine, and British scientists are conducting economic assessments of areas of the Antarctic Peninsula.

The most recent forecasts on the likely exploitation of such mineral resources, however, are pessimistic, highlighting the considerable technological problems likely to be encountered, and stressing that Arctic success and experience are not necessarily transferable to Antarctica.

The present and possibly final stages of negotiations of an Antarctic Minerals Regime (see page 20), and the expected signature of a convention in late May of this year are laudable, since experience elsewhere has shown such agreements and regulations come about only *after* serious environmental damage has been inflicted. However, the legal instruments, when adopted, will require flexibility against changed circumstances to provide the necessary political and legal stability for the investment of venture capital. Among those nations with Antarctic sovereignty claims, there may be a desire on the part of some to establish the mineral potential of their "territory" or "sphere of influence" as part of a long-term plan, valuable, not only in its own right, but as a bargaining element in future treaty negotiations.

For science, furthermore, there is the worrying prospect that knowledge bearing on the economic uses of Antarctica might become proprietary, leading to a reduction in international cooperation in certain research ventures. The perceived proprietary rights and strategic value of results from some geophysical cruises have already been sufficient to cause concern over the availability of data and records under Article III of the treaty.

Conservation and Environmentalism

The rise of the environmental lobby, and widespread concern over conservation of Antarctica and its wildlife, may be seen as a further issue that creates tension in the prosecution of basic science. At one end of the spectrum, science and conservation are drawn together. To practice and implement sound conservation and management policies, a firm knowledge of environmental phenomena, stemming from pure research, is required. At the other extreme, there may be a conflict between the views of conservationists and the perceived needs of

* The 12 original signatories to the Antarctic Treaty were: Argentina, Australia, Belgium, Britain, Chile, France, Japan, New Zealand, Norway, South Africa, the Soviet Union, and the United States. Those countries having decision-making or consultative status are the 12 original and 8 others: Brazil, China, East Germany, India, Italy, Poland, Uruguay, and West Germany. By mid-May of 1988, there were 18 countries that had joined the treaty in the observer, or non-consultative status: Austria, Bulgaria, Canada, Cuba, Czechoslovakia, Denmark, Ecuador, Finland, Greece, Hungary, the Netherlands, North Korea, Papua New Guinea, Peru, Rumania, South Korea, Spain, and Sweden.

** Scientific Committee on Antarctic Research (SCAR)—Scientific Committee on Oceanic Research (SCOR)—Biological Investigations of Marine Antarctic Systems and Stocks (BIOMASS)

The South Pole surrounded by flags of all the Antarctic Treaty countries active in scientific research. In the background is the Amundsen-Scott South Pole Station of the United States. (Photo by C.W.M. Swithinbank, courtesy British Antarctic Survey)

science—with regard to the destruction or modification of small elements of the environment (for example, killing seals and penguins in biological research, causing explosions for geophysical surveys, or the construction of logistic facilities [bases, harbors, and airstrips] in the support of science activity).

There will be an increasing requirement for science projects, if they are likely to damage the environment, to be the subject of Environmental Impact Assessments (EIAs). In some instances, inherent interest in conservation matters, or the political lobby of environmental groups, may be sufficient to redirect significant support into these aspects of Antarctic work away from basic scientific research. Already the Scientific Committee on Antarctic Research (SCAR) and the International Union for the Conservation of Nature and Natural Resources (IUCN) have discussed jointly how to develop and support additional protective measures to conserve the Antarctic environment in the future. There is no doubt that more can be achieved in the way of educating national programs on good conservation practices. Also, more resources will be required to carry out conservation-related studies, whether for EIAs or specific "applied" aspects of science. This may detract from traditional scientific endeavors, causing a shift in the overall balance of science effort within a national program.

Antarctic Science: Shaping the Future

Faced with mounting challenges, can scientific endeavor continue into the 21st Century as a valid and dominant influence in Antarctica? The answer, I believe, is a qualified, but definite, yes. My reservations focus on the need for the judgments which shape the science plans for Antarctica (both national and international) to be more selective and self-critical in search of excellence, to be cost-effective, and, above all, to be responsive to the global forces that act on international research and development policy. Science policymakers must exploit aggressively two principal themes in future years: the scientific uniqueness of Antarctica and Antarctica's global role.

Global Relevance

The perspective provided by almost half a century of scientific investigation demonstrates clearly and without ambiguity the integral role of Antarctica in the natural systems of planet Earth.

In driving the global atmospheric regime, Antarctica acts as a major heat sink. Continental ice sheet volume and sea ice extent provide second order modulating influences on radiation budgets and circulation on a variety of timescales. The effects of man-induced increases of radiatively active gases (for example, carbon dioxide and methane) may have profound effects in the south


a.


b.

Fragmentation of Gondwana, the ancient supercontinent, over the last 200 million years: a) 200 million years ago; b) present-day continental distribution.

polar regions where models predict amplification of temperature. Furthermore, the Southern Ocean plays an influential role as a major sink, particularly for carbon dioxide, for which the estimated uptake is on the order of 30 percent of that discharged into the atmosphere.

The geological history of the Southern Hemisphere tells us there was once a super-continent called Pangaea, which comprised most of the land surface on Earth. Pangaea broke in two about 220 million years ago, with the southern section, called Gondwanaland, drifting south until about 180 to 200 million years ago, when it too split apart, forming what are now known as South America, Africa, India, Australia, and Antarctica. It was not until 1912 that Alfred Wegener suggested that these continents had once been joined together. The geophysical and geological communities did not take this suggestion seriously until the mid-1960s, when the discovery of magnetic anomalies across the mid-Atlantic Ridge led to the concept of sea-floor spreading and the theory of plate tectonics. It was now becoming clear that Antarctica was a central piece in the mosaic of Gondwana.

The Climate and Ozone Questions

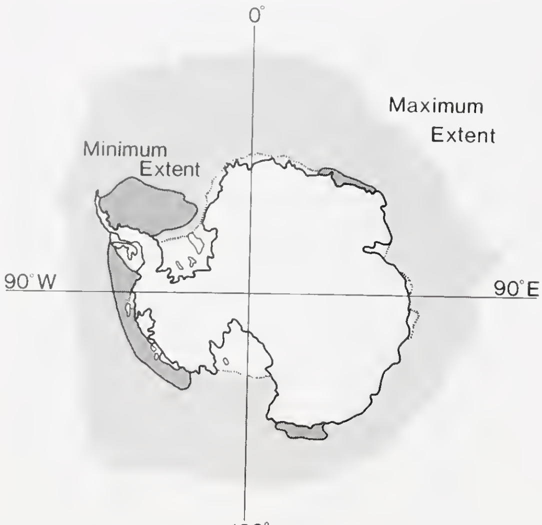
It is too early to evaluate the long-term and global impact of the discovery of the depletion of Antarctic ozone in the austral spring and the likely effects of the Montreal Protocol (1987) to limit chlorofluorocarbon production. The ozone issue, however, has thrust Antarctica onto the world stage in a manner impossible to have predicted. Daily newspapers, popular journals and magazines, and learned scientific publications around the world carry information and updates on the background and implications of the depletion of ozone in the Antarctic springtime stratosphere (see also page 47). From scientist to politician, from journalist to cab driver, ozone is a matter for discussion and of considerable concern. Antarctic scientists must take hold of this opportunity to provide influential and authoritative arguments for governments related to ozone, and which underscore the relevance and timeliness of their research: such opportunities come only once in each generation.

The Antarctic Laboratory

If the above brief examples demonstrate the growing recognition of the wide relevance of Antarctic research, the formulation of future science policy must concentrate on continuing to support those elements of Antarctic investigation which address questions of major regional and/or global concern, and, second, direct resources toward such areas of science, in which Antarctica provides a unique "laboratory." It is senseless to expend monetary and intellectual resources in Antarctica if the problems can be better investigated elsewhere. There are abundant opportunities for exciting and relevant research in Antarctica today.

The ice sheet, which comprises 90 percent of the ice on planet Earth, presents unparalleled scope for the study of past climate and environmental conditions extending back to possibly 1 million years before present. The 2,083 meter-long ice cores from Vostok station retrieved by French and Soviet scientists have disclosed climate details of the last 160,000 years. Isotopes of oxygen and hydrogen are diagnostic of palaeotemperatures; insoluble particulate matter and acids indicate periods of volcanic activity; gas bubble pressures assist in estimating the former elevation of the ice sheet, while the included gas can provide insight into the composition of ancient atmospheres. The identification of carbon dioxide in particular has demonstrated its role in changing climate, and documented the inexorable rise of the concentration of that greenhouse gas in the atmosphere since pre-industrial times. The important monitoring of changes in the global

Emperor penguins, the largest of the seven penguin species found in Antarctic waters. The males are the only warm-blooded animals to spend the bitter winter on the Antarctic continent, while the females winter at sea. The male incubates his mate's single egg by resting it on his feet, tucked under a flap of skin. Later, the newly hatched chick is kept warm in the same way. (Photo by I. Somerton, courtesy of the British Antarctic Survey)



The annual maximum and minimum sea ice extent in Antarctica between 1973 and 1981.

background levels of a variety of materials cycled through the atmosphere is possible from ice cores (besides carbon dioxide, there are methane, nitrate oxide, various nitrate oxide compounds, and sulfur dioxide), and heavy metals (copper, lead, zinc, cadmium) can be measured at picograms per gram levels in recent snowfalls.

The onshore-offshore geological and geophysical study of the narrow, continental-based magmatic arc (where the underthrusting of a crustal plate results in the formation of volcanic island chains) along the Pacific margin of Antarctica and principally in the Antarctic Peninsula, where the geology is relatively simple, is forming an important basis for interpreting destructive plate margins in more complex domains of the Earth's crust. The development of "geotraverse," or geological survey, activities in this and other parts of Antarctica will be relevant and timely.

In the study of geospace (the ionosphere and magnetosphere), the polar regions, and Antarctica in particular, are especially well-favored. The supersonic flow of electrically charged particles emanating from the sun (known as the solar wind) streams past Earth and interacts in a complex manner with the planet's magnetic field. Protons and electrons are directed toward the planet and its ionosphere along magnetic fieldlines, leading to auroral displays and atmospheric disturbances, which are of vital importance for radio communication, and also allow deep-space phenomena to be studied from the ground.

International Coordination of Science

It was recognized quite early in Antarctic science that, in order to be effective, research had to be coordinated to come to terms with the immense size of the continent, the magnitude of the scientific problems, and the logistic requirements—all beyond the reach of a single nation. SCAR was established in 1957 by the International Council of Scientific Unions (ICSU), of which it is a component body, to initiate, promote and coordinate scientific activity in Antarctica, with a view to framing and reviewing scientific programs of circumpolar scope and significance. With 18 full and 7 associate member countries, it meets biennially, and acts through an executive committee, permanent working groups, and more temporary groups ot specialists to report on the main Antarctic scientific disciplines. Increasingly SCAR is being requested to advise and review issues of concern to the Antarctic Treaty System through these mechanisms. Such matters focus on requirements for conservation of marine living resources, waste disposal, and the potential environmental impacts associated with a variety of activities, such as minerals exploitation. SCAR will need to be responsive to these and future overtures if science is to continue to have a strong voice in the wider development of Antarctic affairs.

Some nations have been criticized because science is not foremost in their Antarctic policy. It has been charged that a low-level science effort often is used as a token to gain acceptance to consultative status and hence political presence, notwithstanding Article IX of the treaty, which calls for "substantial" scientific activity. The minimalist approach (as it may be termed) does not augur well for healthy Antarctic science. SCAR must work diligently to ensure wide and adequate participation of nations in the research of the continent and surrounding oceans. This process can be assisted by new lines of scientific enquiry in which Antarctica can play a leading role with research contributions at a variety of levels.

One of these is the ICSU International Geosphere-Biosphere Program, which has identified two major themes: detailed reconstruction of the past, and the accurate determination of current changes on a global scale, with the separation of natural and man-made causes. SCAR will be able to foster coordinated research on past environmental changes, identification of anthropogenic pollutants in polar snows, questions of ice sheet stability, extreme environmental adaptions of living organisms and their changes with time, the role of biological activity in energy flux, and the coupling of the Sun-Earth system through atmospheric investigations focused on certain gases and ozone—all indeed challenges for the future.

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Selected References

Farman, J. C., B. G. Gardiner, and J. D. Shanklin. 1985. Large losses of total ozone in Antarctica reveal seasonal ClO_x/NO_x interaction. *Nature* 315: 207–210.

Genthon, C., J. M. Barnola, D. Raynaud, C. Lorius, J. Jouzel, N. I. Barkov, Y. S. Korotkevich, and M. Kotlyakov. 1987. Vostok ice core: Climatic response to CO_2 and orbital forcing changes over the last climatic cycle. *Nature* 329: 414–418.

Parsons, A. (Chairman) 1987. *Antarctica: The Next Decade*. 164 pp. Cambridge, England: Cambridge University Press.

Walton, D. W. H. (Ed.) 1987. *Antarctic Science*. 280 pp. Cambridge, England: Cambridge University Press.

The Antarctic Treaty

(1959 Text—Ratified 1961)

The Governments of Argentina, Australia, Belgium, Chile, the French Republic, Japan, New Zealand, Norway, the Union of South Africa, the Union of Soviet Socialist Republics, the United Kingdom of Great Britain and Northern Ireland, and the United States of America,

Recognizing that it is in the interest of all mankind that Antarctica shall continue forever to be used exclusively for peaceful purposes and shall not become the scene or object of international discord;

Acknowledging the substantial contributions to scientific knowledge resulting from international cooperation in scientific investigation in Antarctica;

Convinced that the establishment of a firm foundation for the continuation and development of such cooperation on the basis of freedom of scientific investigation in Antarctica as applied during the International Geophysical Year accords with the interests of science and the progress of all mankind;

Convinced also that a treaty ensuring the use of Antarctica for peaceful purposes only and the continuance of international harmony in Antarctica will further the purposes and principles embodied in the Charter of the United Nations;

Have agreed as follows:

Article I

1. Antarctica shall be used for peaceful purposes only. There shall be prohibited, inter alia, any measure of a military nature, such as the establishment of military bases and fortifications, the carrying out of military maneuvers, as well as the testing of any type of weapon.

2. The present Treaty shall not prevent the use of military personnel or equipment for scientific research or for any other peaceful purpose.

Article II

Freedom of scientific investigation in Antarctica and cooperation toward that end, as applied during the International Geophysical Year, shall continue, subject to the provisions of the present Treaty.

Article III

1. In order to promote international cooperation in scientific investigation in Antarctica, as provided for in Article II of the present Treaty, the Contracting Parties agree that, to the greatest extent feasible and practicable:

(a) information regarding plans for scientific programs in Antarctica shall be exchanged to permit maximum economy of and efficiency of operations;

(b) scientific personnel shall be exchanged in Antarctica between expeditions and stations;

(c) scientific observations and results from Antarctica shall be exchanged and made freely available.

2. In implementing this Article, every encouragement shall be given to the establishment of cooperative working relations with those Specialized Agencies of the United Nations and other international organizations having a scientific or technical interest in Antarctica.

Article IV

1. Nothing contained in the present Treaty shall be interpreted as:

(a) a renunciation by any Contracting Party of previously asserted rights of or claims to territorial sovereignty in Antarctica;

(b) a renunciation or diminution by any Contracting Party of any basis of claim to territorial sovereignty in Antarctica which it may have whether as a result of its activities or those of its nationals in Antarctica, or otherwise;

(c) prejudicing the position of any Contracting Party as regards its recognition or non-recognition of any other State's rights of or claim or basis of claim to territorial sovereignty in Antarctica.

2. No acts or activities taking place while the present Treaty is in force shall constitute a basis for asserting, supporting or denying a claim to territorial sovereignty in Antarctica or create any rights of sovereignty in Antarctica. No new claim, or enlargement of any existing claim, to territorial sovereignty in Antarctica shall be asserted while the present Treaty is in force.

Article V

1. Any nuclear explosions in Antarctica and the disposal there of radioactive waste material shall be prohibited.

2. In the event of the conclusion of international agreements concerning the use of nuclear energy, including nuclear explosions and the disposal of radioactive waste material, to which all of the Contracting Parties whose representatives are entitled to participate in the meetings provided for under Article IX are parties, the rules established under such agreements shall apply in Antarctica.

Article VI

The provisions of the present Treaty shall apply to the area south of 60° South Latitude,

including all ice shelves, but nothing in the present Treaty shall prejudice or in any way affect the rights, or the exercise of the rights, of any State under international law with regard to the high seas within that area.

Article VII

1. In order to promote the objectives and ensure the observance of the provisions of the present Treaty, each Contracting Party whose representatives are entitled to participate in the meetings referred to in Article IX of the Treaty shall have the right to designate observers to carry out any inspection provided for by the present Article. Observers shall be nationals of the Contracting Parties which designate them. The names of observers shall be communicated to every other Contracting Party having the right to designate observers, and like notice shall be given of the termination of their appointment.

2. Each observer designated in accordance with the provisions of paragraph 1 of this Article shall have complete freedom of access at any time to any or all areas of Antarctica.

3. All areas of Antarctica, including all stations, installations and equipment within those areas, and all ships and aircraft at points of discharging or embarking cargoes or personnel in Antarctica, shall be open at all times to inspection by any observers designated in accordance with paragraph 1 of this Article.

4. Aerial observation may be carried out at any time over any or all areas of Antarctica by any of the Contracting Parties having the right to designate observers.

5. Each Contracting Party shall, at the time when the present Treaty enters into force for it, inform the other Contracting Parties, and thereafter shall give them notice in advance, of

(a) all expeditions to and within Antarctica, on the part of its ships or nationals, and all expeditions to Antarctica organized in or proceeding from its territory.

(b) all stations in Antarctica occupied by its nationals; and

(c) any military personnel or equipment intended to be introduced by it into Antarctica subject to the conditions prescribed in paragraph 2 of Article I of the present Treaty.

Article VIII

1. In order to facilitate the exercise of their functions under the present Treaty, and without prejudice to the respective positions of the Contracting Parties relating to jurisdiction over all other persons in Antarctica, observers designated under paragraph 1 of Article VII and scientific personnel exchanged under sub-paragraph 1(b) of Article III of the Treaty, and members of the staffs accompanying any such persons, shall be subject only to the jurisdiction of the Contracting Party of which they are nationals in respect of all acts or omissions occurring while they are in Antarctica for the purpose of exercising their functions.

2. Without prejudice to the provisions of paragraph 1 of this Article, and pending the adoption of measures in pursuance of sub-paragraph 1(e) of Article IX, the Contracting Parties concerned in any case of dispute with regard to the exercise of jurisdiction in Antarctica shall immediately consult together with a view to reaching a mutually acceptable solution.

Article IX

1. Representatives of the Contracting Parties named in the preamble to the present Treaty shall meet at the City of Canberra within two months after the date of entry into force of the Treaty, and thereafter at suitable intervals and places, for the purpose of exchanging information, consulting together on matters of common interest pertaining to Antarctica, and formulating and considering, and recommending to their Governments, measures in furtherance of the principles and objectives of the Treaty, including measures regarding:-

(a) use of Antarctica for peaceful purposes only;
(b) facilitation of scientific research in Antarctica;
(c) facilitation of international scientific cooperation in Antarctica;
(d) facilitation of the exercise of the rights of inspection provided for in Article VII of the Treaty.
(e) questions relating to the exercise of jurisdiction in Antarctica;
(f) preservation and conservation of living resources in Antarctica.

2. Each Contracting Party which has become a party to the present Treaty by accession under Article XIII shall be entitled to appoint representatives to participate in the meetings referred to in paragraph 1 of the present Article, during such times as that Contracting Party demonstrates its interest in Antarctica by conducting substantial scientific research activities there, such as the establishment of a scientific station or the dispatch of a scientific expedition.

3. Reports from the observers referred to in Article VII of the present Treaty shall be transmitted to the representatives of the Contracting Parties participating in the meetings referred to in paragraph 1 of the present Article.

4. The measures referred to in paragraph 1 of this Article shall become effective when approved by all the Contracting Parties whose representatives were entitled to participate in the meetings held to consider those measures.

5. Any or all of the rights established in the present Treaty may be exercised as from the date of entry into force of the Treaty whether or not any measures facilitating the exercise of such rights have been proposed, considered or approved as provided in this Article.

Article X

Each of the Contracting Parties undertakes to exert appropriate efforts, consistent with the Charter of the United Nations, to the end that no one engages in any activity in Antarctica contrary to the principles or purposes of the present Treaty.

Article XI

1. If any dispute arises between two or more of the Contracting Parties concerning the interpretation or application of the present Treaty, those Contracting Parties shall consult among themselves with a view to having the dispute resolved by negotiation, inquiry, mediation, conciliation, arbitration, judicial settlement or other peaceful means of their own choice.

2. Any dispute of this character not so resolved shall, with the consent, in each case, of all parties to the dispute, be referred to the International Court of Justice for settlement; but failure to reach agreement on reference to the International Court shall not absolve parties to the dispute from the responsibility of continuing to seek to resolve it by any of the various peaceful means referred to in paragraph 1 of this Article.

Article XII

1. (a) The present Treaty may be modified or amended at any time by unanimous agreement of the Contracting Parties whose representatives are entitled to participate in the meetings provided for under Article IX. Any such modification or amendment shall enter into force when the depositary Government has received notice from all such Contracting Parties that they have ratified it.

(b) Such modification or amendment shall thereafter enter into force as to any other Contracting Party when notice of ratification by it has been received by the depositary Government. Any such Contracting Party from which no notice of ratification is received within a period of two years from the date of entry into force of the modification or amendment in accordance with the provision of subparagraph 1(a) of this Article shall be deemed to have withdrawn from the present Treaty on the date of the expiration of such period.

2. (a) If after the expiration of thirty years from the date of entry into force of the present Treaty, any of the Contracting Parties whose representatives are entitled to participate in the meetings provided for under Article XI so requests by a communication addressed to the depositary Government, a Conference of all the Contracting Parties shall be held as soon as practicable to review the operation of the Treaty.

(b) Any modification or amendment to the present Treaty which is approved at such a Conference by a majority of the Contracting Parties there represented, including a majority of those whose representatives are entitled to participate in the meetings provided for under Article IX, shall be communicated by the depositary Government to all Contracting Parties immediately after the termination of the Conference and shall enter into force in accordance with the provisions of paragraph 1 of the present Article.

(c) If any such modification or amendment has not entered into force in accordance with the provisions of sub-paragraph 1(a) of this Article within a period of two years after the date of its communication to all the Contracting Parties, any Contracting Party may at any time after the expiration of the period give notice to the depositary Government of its withdrawal from the present Treaty; and such withdrawal shall take effect two years after the receipt of the notice by the depositary Government.

Article XIII

1. The present Treaty shall be subject to ratification by the signatory States. It shall be open for accession by any State which is a Member of the United Nations, or by any other State which may be invited to accede to the Treaty with the consent of all the Contracting Parties whose representatives are entitled to participate in the meetings provided for under Article IX of the Treaty.

2. Ratification of or accession to the present Treaty shall be effected by each State in accordance with its constitutional processes.

3. Instruments of ratification and instruments of accession shall be deposited with the Government of the United States of America, hereby designated as the depositary Government.

4. The depositary Government shall inform all signatory and acceding States of the date of each deposit of an instrument of ratification or accession, and the date of entry into force of the Treaty and of any modification or amendment thereto.

5. Upon the deposit of instruments of ratification by all signatory States, the present Treaty shall enter into force for those States and for States which have deposited instruments of accession. Thereafter the Treaty shall enter into force for any acceding State upon the deposit of its instruments of accession.

6. The present Treaty shall be registered by the depositary Government pursuant to Article 102 of the Charter of the United Nations.

Article XIV

The present Treaty, done in the English, French, Russian and Spanish languages, each version being equally authentic, shall be deposited in the archives of the Government of the United States of America, which shall transmit duly certified copies thereof to the Governments of the signatory and acceding States.

The Antarctic Treaty System

by Lee A. Kimball

The pace of science, law, and politics continues to quicken in the Antarctic. The existing international agreements and management programs are responding to new pressures. Overfishing continues to be a problem, now joined by the possibility of minerals exploitation. Criticisms have been leveled at pollution and environmental protection practices, and on the "openness" of Antarctic decision-making—with an increased role by the United Nations (and Third-World countries) in the Antarctic under discussion in the United Nations General Assembly.

Then there is 1991. The language of the original 1959 Antarctic Treaty allows that, after a 30-year period, any treaty party may call for a review of the treaty. Despite some misperceptions, the treaty does not expire in 1991, nor will it necessarily be reviewed or changed. However, the option, and perhaps some uncertainty, do exist.

The challenges of the future are to integrate Antarctic science and policy to realize the global benefits from Antarctic science, avoid environmental damage to the area, and preserve widespread international support for an agreed system of governance in Antarctica.

Antarctic Treaty Signatories

Category/Country	Date of Ratification	Ratification Sequence
I. Original Consultative Parties (12)		
a. Claimant states (7)		
Britain	31 May 1960	1
Norway	24 Aug 1960	6
France	16 Sep 1960	7
New Zealand	1 Nov 1960	8
Argentina	23 Jun 1961	11
Australia	23 Jun 1961	12
Chile	23 Jun 1961	13
b. Non-claimant states (5)		
South Africa	21 Jun 1960	2
Belgium	26 Jul 1960	3
Japan	4 Aug 1960	4
United States	18 Aug 1960	5
Soviet Union	2 Nov 1960	9
II. Later Consultative Parties (8) (Date in parentheses is the date Nation became a Consultative Party)		
Poland (29 Jul 1977)	8 Jun 1961	10
Brazil (12 Sep 1983)	16 May 1975	19
West Germany (3 Mar 1981)	5 Feb 1979	21
Uruguay (7 Oct 1985)	11 Jan 1980	22
China (7 Oct 1985)	8 Jun 1983	27
India (12 Sep 1983)	19 Aug 1983	28
Italy (5 Oct 1987)	18 Mar 1981	24
East Germany (5 Oct 1987)	19 Nov 1974	18
III. Non-Consultative Parties (18)		
Czechoslovakia	14 Jun 1962	14
Denmark	20 May 1965	15
Netherlands	30 Mar 1967	16
Rumania	15 Sep 1971	17
Bulgaria	11 Sep 1978	20
Papua New Guinea[1]	16 Mar 1981	23
Peru	10 Apr 1981	25
Spain	31 Mar 1982	26
Hungary	27 Jan 1984	29
Sweden	24 Apr 1984	30
Finland	15 May 1984	31
Cuba	16 Aug 1984	32
South Korea	28 Nov 1986	33
Greece	8 Jan 1987	34
North Korea	21 Jan 1987	35
Austria	25 Aug 1987	36
Ecuador	15 Sep 1987	37
Canada	4 May 1988	38

[1] Papua New Guinea became a member of the treaty by succession after it became independent of Australia.

Antarctica, 1959 to 1977

The Antarctic Treaty was concluded in 1959 to preserve Antarctica and its surrounding area for peaceful purposes only, and to promote cooperative scientific investigation in the region. These relatively modest aims conceal a mandate that has demilitarized a tenth of the Earth's surface and provided the conduit for any interested nation to carry out scientific research in Antarctica. An example of this research was most recently demonstrated by multinational scientific investigations of the causes of the Antarctic "ozone hole" (see page 47).

For many years, until the mid- to late-1970s, Antarctica remained a quiet backwater for exploration and scientific research of primarily local or regional significance. Every two years, the 12 original signatories to the Antarctic Treaty (see adjacent table) met to consider pending issues and problems. During this period, seven other countries acceded to the Treaty, but they were not entitled to attend the biennial Antarctic Treaty Consultative Meetings (ATCMs). For the most part, the Antarctic Treaty Consultative Parties (ATCPs) demonstrated great foresight in their management of Antarctica:

- *They took advantage of the vehicle of science to side-step conflicting views about the territorial status of Antarctica;*
- *They established an on-going "consultative" mechanism to address new issues and problems as they arose; and*
- *They took note of the special nature of the Antarctic continent and its surroundings and*

Selected stations and physical features of Antarctica.

declared all of Antarctica a "special conservation area" (ATCM Recommendation III-8, Agreed Measures for the Conservation of Antarctic Fauna and Flora, adopted in 1964).

As human activities in Antarctica have grown and intensified, the ATCPs have responded within the mandate of the Antarctic Treaty to produce additional measures and treaties to regulate these new activities. However, every time they seek agreement on a new measure, they must once again find a balance that preserves the positions of both countries claiming territory in Antarctica and those that do not recognize any claims (see map page 23). On this basis, the ATCPs have adopted 164 recommendations at the 14 biennial meetings held to date.

These recommendations deal with such matters as safety of operations and logistics in Antarctica; environmental protection (to avoid undermining the continent's relatively pristine value for the conduct of scientific research); regulation of tourism; and procedures to ensure advance notice of national research plans and public availability of the results.

In addition, the ATCPs have concluded three more treaties: the 1972 Convention for the Conservation of Antarctic Seals (CCAS), which entered into force in 1978; the 1980 Convention on the Conservation of Antarctic Marine Living Resources (CCAMLR), which entered into force in 1982; and the Antarctic Minerals Convention, adopted in May 1988, and open for signature later this year (see page 20).

All of these forums draw on the technical and scientific expertise of the Scientific Committee on Antarctic Research (SCAR), whose members set in motion the 1957–58 International Geophysical Year (IGY) that laid the groundwork for agreement on the Antarctic Treaty. SCAR, headquartered in Cambridge, England, is a component of the International Council of Scientific Unions (ICSU), a nongovernmental planning and coordinating body with its main offices in Paris, France. The SCAR membership comes from countries interested and active in Antarctic affairs, and its national committees represent a vast storehouse of experience in Antarctic science and logistics. SCAR meets every other year, in alternative years to ATCMs.

The Antarctic agreements identified previously, together with SCAR, constitute the

Antarctic Treaty System (ATS). Where ATCMs and the meetings of the institutions established pursuant to the other Antarctic treaties handle legal and political matters of interest to governments, SCAR's purpose is to serve as the crucible for identification and coordination of scientific research programs in Antarctica.

The Onset of Change

The last decade has witnessed a surge of activity in Antarctica. Several countries have launched commercial fishing operations in the Southern Ocean. The discovery of traces of hydrocarbons in 1972–73 aroused interest in the possibility of offshore minerals development. Tourism has grown substantially, especially during the last two years, and the number of countries conducting scientific research in Antarctica has virtually doubled. Antarctica's resources potential focused world attention on the region, both from countries interested in the resources and from scientists and environmentalists bent on protecting Antarctica from spoilage.

By mid-May of 1988, 26 additional nations had joined the treaty, 8 of which have achieved "consultative" status. In 1983—at the request of Malaysia and Antigua and Barbuda—and in every subsequent year, the United Nations General Assembly has considered the question of Antarctica. Several countries that are not party to the Antarctic Treaty have challenged the rights of the ATCPs to assume the governance of Antarctic affairs and advocated that the United Nations take over.

Last but not least, the type of scientific research carried out in Antarctica has turned more and more toward large-scale, interdisciplinary programs exploring phenomena of global significance, such as plate tectonics, oceanic circulation, and the formation of world climate and weather patterns.

Antarctica in the limelight has for the most part produced good results. The ATCPs have been forced to confront the record of how well they have lived up to the foresight demonstrated by those who conceived of and executed the IGY and the structuring of the ATS. They have been challenged primarily on two fronts: conservation and environmental protection in Antarctica, and the "openness of the ATS." As progress is made in addressing these issues, however, new challenges are emerging.

The Environmental Challenge

Whether from external criticism or from internal assessment, it became clear in the early 1980s that the Antarctic Treaty mechanism should address in a systematic, comprehensive manner questions of pollution and environmental protection.

In 1983, the Antarctic Treaty Consultative Meeting, ATCM XII, initiated consideration of environmental impact assessment procedures for science and logistics activities in Antarctica and called for revision of the code governing waste disposal in Antarctica (ATCM Recommendation VIII-11, Code of Conduct for Antarctic Expeditions and Station Activities). At the next meeting, in 1985, ATCM XIII launched discussion of a long-term conservation strategy for Antarctica, and in 1987, ATCM XIV examined ideas for developing a Code of Conduct for Tourism in Antarctica, and on the development and application of sophisticated land-use planning and zoning techniques to deal with multiple uses of Antarctic continental and marine spaces.

In 1987, after four years, the environmental impact assessment procedures were finally adopted (when all parties will actually implement them is unknown). The waste disposal code has yet to be updated, although it is expected that this will occur at ATCM XV in 1989.

Nevertheless, ATCM XIV crossed a major threshold in acknowledging that new, more comprehensive arrangements are required to manage and protect Antarctica, and that protective measures must be extended to marine areas. By encouraging a review of the effectiveness of existing waste disposal and protective arrangements, it also recognized the need to document present practices and their effects as a basis for seeking improvements.

These protective approaches long have been advocated by environmentalists and some Antarctic scientists. They also are being addressed in the preparation of a long-term plan for Antarctic conservation, which is being drawn up under the auspices of the International Union for the Conservation of Nature and Natural Resources (a nongovernmental conservation organization with headquarters in Gland, Switzerland), in collaboration with SCAR. As these initiatives come to fruition, they would permit the ATCPs to regain the high ground in giving effect to Antarctica's status as a special conservation area.

Coordinated Science

A coordinated approach to Antarctic conservation and management requires the collection, organization, and accessibility of scientific data that can meet the needs of Antarctica's managers. If managers are to better anticipate and plan for expanding activities in Antarctica, they will have to have available time-series monitoring data 1) identifying the effects of human activities in Antarctica, and 2) distinguishing the effects of these activities from natural variability in the Antarctic environment. This information will ultimately promote the development of predictive capabilities.

The ATCPs are taking fledgling steps in the direction of improving the comparability and accessibility of scientific data on Antarctica, in consultation with SCAR. As in many other fields of science today, however, the advent of satellite data-collection and computer modeling techniques are opening new vistas in these areas that human capabilities have yet to apprehend fully. These efforts could be greatly enhanced through effective international coordination, and collaborative ventures could increase the cost-effectiveness of individual national programs.

Questions of data collection and management, and the design of scientific research programs responsive to the needs of managers are also at the top of the agenda of the annual meetings

Two mature elephant seals during a territorial dispute. Their inflated noses help produce a resonating roar to ward off rivals. Elephant seals are one of the species protected under the CCAMLR treaty. (Photo courtesy British Antarctic Survey)

that take place under CCAMLR. The 1987 meeting honed in on defining a detailed strategy to implement the far-sighted "ecosystem standard"* for conservation of marine living resources, with particular emphasis on the need to accelerate the articulation of monitoring and conservation strategies for krill. Although data collection and handling procedures are more advanced under CCAMLR than those related to Antarctica generally, implementation of CCAMLR would still benefit from continuing cooperation in utilizing existing data sets and future collaborative programs.

Lastly, countries active in Antarctica will have to develop and fund scientific research and data collection programs that can supplement and verify the information submitted by countries with a vested interest in resources exploitation.

* The "ecosystem standard" contained in the 1980 Convention on the Conservation of Antarctic Marine Living Resources (CCAMLR) states that harvesting is not supposed to decrease a population to levels below those that allow stable replenishment. If populations are already depleted, they are supposed to be restored. In addition, signatories must maintain ecological relationships among species, and prevent changes in the marine ecosystem that are not potentially reversible over two or three decades. The scientists involved, however, are still struggling to determine how best to give effect to this standard.

The Openness Challenge

As ATCM policies have evolved, so too have debates in the United Nations General Assembly undergone subtle shifts since 1983. Initially, nontreaty countries criticized the ATS for the "secrecy" with which meetings are conducted, the "exclusivity" of the group of countries active in Antarctica that could afford to carry out "substantial" research activities and thus qualify for decision-making status, and the presence in ATS forums of the apartheid regime of South Africa.

As more information has been made available on ATS meetings and activities in Antarctica, there has been less complaint about the lack of information on Antarctica *except* in relation to the negotiation of the Antarctic Minerals Convention. In 1986 and 1987, the UN General Assembly resolutions on Antarctica drew more attention to the minerals issue by calling for a moratorium on these negotiations until all members of the international community could participate fully in them.

Second, many nations that were initially demanding that Antarctica be declared the "common heritage of mankind," and administered under United Nations auspices, today seem more willing to consider alternative arrangements. These alternatives would be consistent with common heritage principles, without calling for actual internationalization of the area—which would undermine the careful balance struck by the treaty in

preserving the positions of both claimant and nonclaimant states.

Instead, the nations "outside" the existing decision-making structure have advocated that more extensive relationships between existing international organizations in the United Nations system and the ATS would allow the views of the wider international community to be expressed in ATS forums, and establish accountability to the broader international membership of UN organizations. In this regard, the initiative in the General Assembly in 1986 to have the United Nations act as a central repository for information on ATS meetings and activities, and the attempt in 1987 to have the ATCPs invite the UN Secretary-General to attend ATCMs and the minerals regime negotiations and report back to the General Assembly, may succeed *if* they are developed on a cooperative basis among all nations concerned. As indicated by the Malaysian representative in 1987, "in this way the international community could be involved, even if indirectly, in Antarctica, and it would also be able to judge if its interests and concerns are being accommodated."

Third, there has been a bit of a reversal among critics in the UN on the role of the Non-consultative Parties within ATCMs. Where in 1983–84 the critics were willing to wait and see how the influence of these nonvoting parties in their new observer role evolved, in 1986–87 the critics attacked the mere existence of the ATS' restricted decision-making system in today's era of international "democratization."

The Response

In 1983, ATCM XII took the first important step in responding to these criticisms, voiced later that fall in the UN General Assembly debates. It invited the Nonconsultative Parties to attend meetings as observers; provided for the possibility that observers from international organizations, such as the United Nations specialized agencies or SCAR, could be invited to ATCMs to contribute to discussions within their areas of expertise; began to declassify documentation from prior ATCMs; and agreed in general to provide a more ample public record of ATCMs, and circulate this to the United Nations and other interested organizations and individuals.

Major additional strides were taken by ATCM XIII in 1985, and ATCM XIV in 1987. The ATCPs continued to expand the public record of ATCMs and created national centers for dissemination of information. ATCM XIV finally acted on the 1983 mandate to invite representatives of international organizations to attend meetings as observers, and provided for the further development of relationships with them. ATCM XIV also instituted a procedure where other elements of the ATS—SCAR and CCAMLR—report to the consultative meeting on relevant developments to help identify, among other things, issues requiring coordination among different ATS institutions.

Compliance

Compliance with measures adopted by the ATS is an issue related to both environmental concerns and the international community's desire to be informed about the workings of the ATS. Few countries active in Antarctica carry out inspections as provided for under the Antarctic Treaty, and fewer still make their inspection reports public. Moreover, parties to the treaty have traditionally been reluctant to "rock the boat" by asking too many questions about each other's activities in Antarctica.

ATCM XIV represented a significant departure in this regard, as countries began to exchange information on a variety of national practices—the planning and conduct of inspections; approval of ATCM Recommendations; waste disposal, environmental impact assessments, and dealings with tour groups; and on the review of protective arrangements.

Reports on national practice in Antarctica can serve as a basis for evaluating and improving the effectiveness of how ATCM measures are implemented in Antarctica, and whether they are being complied with. National reporting requirements are now commonplace in international agreements, including under CCAMLR and the Antarctic Minerals Convention, so it is an anomaly that the older Antarctic Treaty does not require this of its signatory countries. Also, carrying out the reporting requirement will improve communication within each government between the program managers responsible for science and logistics activities in Antarctica and the policymakers who approve standards and regulations applicable to them.

Another means to ensure compliance with Antarctic measures is to provide for outside scrutiny of actions contemplated and taken. The increasing public availability of records of meetings and activities in Antarctica is helpful in this regard, as are procedures for observer participation in meetings, by both nonvoting nations and international organizations. Observers in meetings should have the option to review and comment on issues and documentation under discussion. However, the observer role in this area has yet to be developed fully.

The Challenges of the Future

Although its time has not yet come, the possibility of establishing a permanent secretariat under the Antarctic Treaty was discussed extensively at ATCM XIV.

At the moment, the Antarctic Treaty has no permanent secretariat, although a secretariat has been established under CCAMLR. The SCAR secretariat, consisting of a part-time executive secretary and a full-time assistant, and devoted only to the coordination of Antarctic scientific activity, has been severely strained at times by requests from the Consultative Parties. Even though an Antarctic Treaty secretariat might have value, some ATCPs are fearful of "bureaucratizing" the Antarctic Treaty, and some claimant nations are fearful that further "internationalization" of the ATS could detract from the special circumstances of Antarctica, which require a delicate balancing of claimant and nonclaimant interests.

Yet, a secretariat could serve as an important source of continuity and expedite communication of information and documentation on the more varied and complicated issues facing ATCMs today. As the Antarctic family grows and the Antarctic agenda expands, it may no longer be appropriate for ATCMs to move as slowly as they have been in adopting, approving, and enforcing measures applicable in Antarctica.

A secretariat also could enhance the liaison within and beyond the ATS. This becomes particularly important in realizing the benefits of international collaboration in basic scientific research programs, and in the more applied monitoring programs.

Coordination must occur among the policymakers responsible for articulating and enforcing measures applicable in Antarctica, the scientific community represented by SCAR, and those responsible within national governments for managing Antarctic research programs and logistics facilities.

The type and balance of science done in the Antarctic also presents a challenge. Antarctic scientists must be prepared to devote some of their skills and resources to analyses tailored to management needs. Otherwise, they may be forced to contemplate a more active form of management by policymakers and program managers of the directions taken and funded. SCAR has already nodded in this direction with the creation of the Group of Specialists on Southern Ocean Ecology, which among other things, is to respond to requests for scientific advice from the Antarctic Treaty and CCAMLR, and the new Group of Specialists on Antarctic Environmental Affairs and Conservation, whose terms of reference are to be developed and approved this year.

Scientists and science program managers could usefully devote more attention to facilitating broader international participation in Antarctic research programs among interested individuals and nations. Some participants in the UN General Assembly debate have suggested the establishment of international stations for scientific research where interested scientists from developing nations unable to afford their own research programs would be welcome. (This idea has been supported by the Polar Research Board, the U.S. National Committee for SCAR. Its publication *U.S. Research in Antarctica in 2000 A.D. and Beyond: A Preliminary Assessment,* 1986, suggests internationalizing access and cooperation at some of the U.S. facilities in Antarctica.)

Lastly, program managers and policymakers may have to combine forces to focus on another impending and interrelated set of issues: the "activities criterion" for decision-making status in ATS forums, and problems arising from increasing concentration of research stations and logistics facilities in Antarctica. As long as the ATCPs interpret the activities criterion to mean establishment of a permanent research station in Antarctica, countries seeking ATCP status for political reasons will increase the potential for interference among stations and logistics, increase the possibility of adverse cumulative impacts on the Antarctic environment, diminish opportunities to conduct research in undisturbed areas, and perhaps foster unproductive duplication of research.

While it is unlikely that the criterion itself will change, the manner in which it is interpreted warrants re-examination by the ATCPs. International research programs that employ facilities shared by scientists from several countries, and reduce the need for separate national facilities, could ease the problem of concentration of activities (and demands on the environment) caused by the location of several stations in a small area, and reduce criticisms of the ATS on the basis of its "exclusivity."

As the possibility of review of the Antarctic Treaty approaches in 1991, three key issues should form the core of the ATCM agenda: establishment of an Antarctic Treaty System secretariat; addressing the interpretation of requirements for consultative status; and the related questions of increased collaboration and coordination among research and monitoring programs—drawing on the combined expertise of policymakers, scientists, and science program managers.

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Selected Readings

Scientific Committee on Antarctic Research. 1987. *International Research in Antarctica*. Cambridge, England: Oxford University Press.

Mitchell, B. 1988. Undermining Antarctica. *Technology Review* 91(2): 48–57.

Orrego-Vicuna, F. 1987. *Antarctic Bibliography* (with particular reference to the legal and political issues of cooperation and the regime on mineral resources). Santiago, Chile: Institute of International Studies, University of Chile.

Polar Research Board. 1986. *Antarctic Treaty System: An Assessment,* Proceedings of a Workshop held at Beardmore South Field Camp, Antarctica, January 7–13, 1985. Washington, D.C.: National Academy Press.

Triggs, G. 1987. *The Antarctic Treaty regime: Law, Environment and Resources. 239 pp.* Cambridge, England: Cambridge University Press.

The Antarctic Mineral

by R. Tucker Scully

EDITOR'S NOTE: The 20 consultative nations adopted the Antarctic Minerals Convention on 2 June 1988, the U.S. State Department reported. The convention, it added, would be signed and ratified at a later date.

The 20 Antarctic Treaty Consultative Parties* (ATCPs) met in Wellington, New Zealand, from May 2 to June 2, 1988, in an effort to complete negotiation of a treaty to deal with possible mineral resource activities in Antarctica. (The 17 other parties to the Antarctic Treaty that are not Consultative Parties were invited as observers.) Talks on such an agreement began six years ago, also in Wellington. At that time, the ATCPs committed themselves to reach an agreed system for determining the acceptability of possible mineral resource activities in Antarctica, and for governing any such activities judged acceptable.

Resource Potential Unknown

Though speculative estimates have been made, the mineral resource potential of Antarctica is unknown. It is, therefore, impossible to predict if, or when, commercial interest in mineral resource exploration or development in Antarctica might emerge. The ATCPs, however, have agreed that it is important to have in place an effective mechanism for the decisions that would be necessary if such interest arises. The objective is to ensure that the possibility of mineral resource activities does not become a source of discord or conflict in Antarctica, and that rigorous environmental criteria are applied to any decisions about such activities. Negotiation of an effective mechanism to achieve these purposes is best undertaken prior to, rather than after, coalescence of resource appetites.

The agreement on the table was of necessity of a framework character, setting forth the obligations and machinery necessary to establish the legal basis for mineral resource activities in Antarctica, and the means for determining if, when, and under what conditions, mineral resource exploration and development may occur. For this reason, the negotiating instrument did not set forth detailed provisions regarding mining activities, but established the process of how detailed terms and conditions would be developed when the need arises. In this regard, the agreement differs from the approach taken in the deep seabed mining provisions of the United Nations Convention on the Law of the Sea, which sought to address in detail possible manganese nodule mining.

The agreement offers the means for development of a wide range of possible resources, from hydrocarbons to hard rock ores, and in various possible areas—onshore or offshore. Under its provisions, the initial stage of mineral resource activity—prospecting—would be permitted without prior authorization by the institutions, although it would be subject to generally applicable environmental and safety standards.

Exploration and development would require prior authorization by the institutions, which would grant exclusive rights to individual operators. The agreement negotiating draft did not contain detailed regulations governing exploration and development. Rather, it incorporated general standards for judging whether, and under what conditions, mineral resource exploration and/or development would be permitted in general areas, and, if permitted, for judging specific applications of such activities. These standards included provisions that no mineral resource activities take place until there exists sufficient information to judge their possible impacts, and until it is judged, based on assessment of those impacts, that there would not be adverse environmental impacts.

Regulatory Committee Proposed

The system envisaged in the agreement rests on the assumption that there are areas of Antarctica that form coherent units for resource management purposes. The process would be initiated by the identification of a general area for a particular resource or resources. Any party could propose that the principal institution, the commission, identify an area. In determining to identify an area, the commission would be required to satisfy itself that such activities would be consistent with the general standards of the agreement, and to configure the area in such fashion, that in view of its physical, geological, and environmental characteristics, it represented a logical resource management unit. The identification of a general area would not constitute a decision to authorize a particular exploration and development project in the area concerned. Rather, it would be a threshold decision, triggering the elaboration of specific requirements for exploration and development, and subsequently, consideration of any specific exploration and development proposals.

* Argentina, Australia, Belgium, Brazil, Britain, Chile, China, East Germany, West Germany, France, India, Italy, Japan, New Zealand, Norway, Poland, South Africa, the Soviet Union, the United States, and Uruguay.

Resources Negotiations

A limited membership institution—a regulatory committee—would be established for each area identified. The regulatory committee would be composed of approximately 10 members, comprising parties most directly interested in the area concerned, and, subject to review by the commission, would set forth the requirements to which any applicants for exploration and development in the area must conform. Following establishment of the requirements, the regulatory committee would be responsible for judging specific application for rights to specific sites. It also would monitor the conduct of any activities undertaken pursuant to an approved application, including review of any proposals to proceed from exploration to development.

Fulfillment by the ATCPs of their commitment to achieve an agreement on this basis is a challenging task. The agreement will have to be acceptable to socialist and nonsocialist countries; to developed and developing countries; and, most particularly, to those claiming territorial sovereignty in Antarctica; and finally, those, like the United States, that neither assert nor recognize such claims—all of whom are represented among the ATCPs. The agreement also will need to accommodate the interests of the international community as a whole. It must be open and balanced, not only to respond to those who have challenged the Antarctic Treaty system in the United Nations and elsewhere, but, more importantly, to achieve its purposes of maintaining Antarctica as the only area of the planet set aside exclusively for peaceful purposes.

Important issues were on the agenda in Wellington. These included the decision-making provisions of the institutions to be established. A balance is required between those who wish to apply the principle of consensus, and those who fear that such provisions could be used to block operation of the system. The issues included the question as to whether the agreement should incorporate provisions to encourage joint participation in future mineral resource activities, should they occur. They also included the complex task of ensuring that effective provisions relating to liability apply to any permitted mineral resource activities, and that there are effective procedures for settlement of disputes over such activities.

The United States, for its part, participated in the Wellington session with the objective of achieving an acceptable agreement—based on the existing framework approach—one that will not only satisfy its environmental and resource concerns, but also the full range of its interests in Antarctica, including a commitment to maintain the world's southernmost region as a zone of peace.

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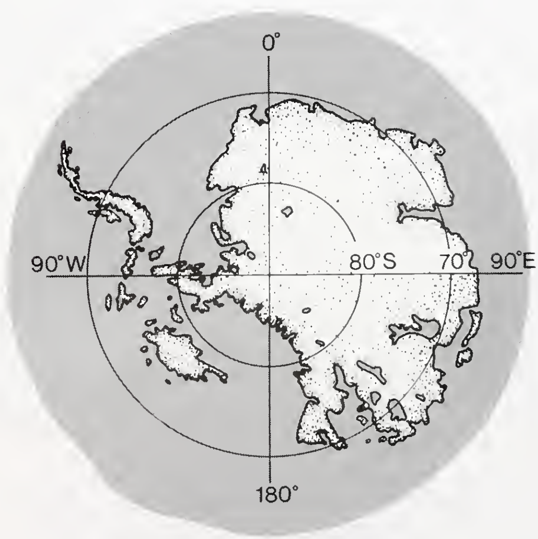


If the ice sheets were removed and the bedrock allowed to adjust, to compensate for the change in weight, the Antarctic coastline would probably look like this.

The Antarctic Legal Regime and the Law of the Sea

by Christopher C. Joyner

Applying international ocean law often hinges on the legal status of the adjoining land. For example, the commonly used definitions—territorial sea, Exclusive Economic Zone, and high seas—denote varying amounts of sovereignty accorded to the coastal state/country, and similarly varying freedoms accorded to the balance of the international community.

But, Antarctica is the only continent without recognized sovereign countries. Because aspects of the international law relating to the continent are therefore ambiguous, the application of ocean law to its surrounding waters also is ambiguous.

Taken by themselves, the legal systems governing primarily the continent (the Antarctic Treaty System) and the surrounding waters (the United Nations Law of the Sea Convention) are open to considerable debate. Taken together, they present a tangle of legal questions.

Although the multinational regime administering the region clearly accepts the proposition that the Law of the Sea applies to the circumpolar waters of the Southern Ocean, fundamental questions turn on which aspects of contemporary ocean law are relevant to the Antarctic, and what maritime rights and duties are applicable to which countries over what parts of the region. The 1982 UN Convention on the Law of the Sea (UNCLOS) did little to resolve these issues. In fact, certain aspects of this "new" Law of the Sea have actually presented more pressing legal concerns over jurisdictional responsibilities and uses of Antarctic waters.

As a result, the late 1980s are an interesting period for Antarctic law—as diverse national views and international legal agreements are being tested and blended, and as nations seek new levels of international cooperation on the lands and waters surrounding the South Pole.

The Antarctic Treaty System

The regime presently governing activities on and around the continent was created in 1959 by the Antarctic Treaty. The Antarctic Treaty applies to the area south of 60 degrees South latitude, including all ice shelves. This agreement provides for demilitarization, denuclearization, and peaceful uses only of the region (see page 11); freedom of scientific research and cooperation; open, unannounced onsite inspection; and the obligation to settle disputes peacefully.

Twenty states today comprise the "Antarctic Treaty Consultative Parties" (ATCPs), who under the treaty are responsible for making policy in the treaty area (page 14). To supplement the Antarctic Treaty, over the last two decades the ATCPs have negotiated other agreements directly related to resource management and ocean law.

First, the Convention for the Conservation of Antarctic Seals was promulgated in 1972, with the express purpose of limiting the vulnerability of seals to commercial exploitation in the region. Second, in 1980 the Convention on the Conservation of Antarctic Marine Living Resources (CCAMLR) was negotiated. This treaty, which entered into force in 1982, is designed primarily to foster conservation and prudent management of krill fisheries in the Southern Ocean. Third, since 1982 the ATCPs have been involved in a series of negotiations aimed at establishing a treaty-based minerals regime. The jurisdictional scope of this Antarctic Minerals Convention will cover mineral-related activities on, in, and around the continent south of 60 degrees South latitude. These activities might include mineral exploitation of the ice shelves, and the seabed and subsoil of adjacent offshore areas. Collectively, these multinational agreements comprise the Antarctic Treaty System, which has administered policy in the region since 1961.

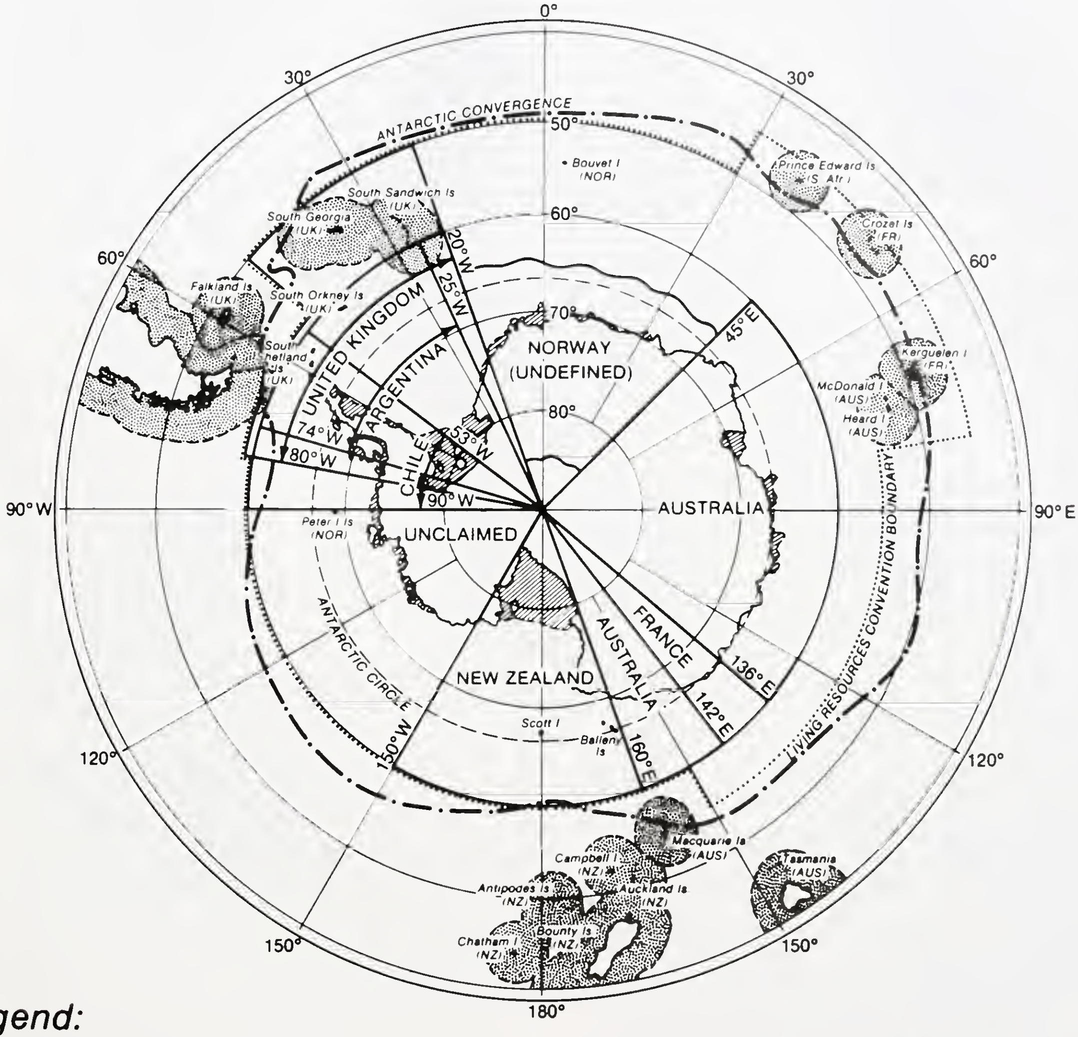
Confusing the Antarctic legal situation is the fact that earlier during this century seven countries made sovereign claims to pie-shaped portions of the continent (page 23). Political complications among the Antarctic countries have been avoided by a provision in the Antarctic Treaty that essentially freezes the status quo of the claims prior to the treaty without accepting, denying, qualifying or clarifying their legal character under international law. Therefore, the treaty can function smoothly by allowing parties to agree to disagree over the status of the claims.

The "New" Law of the Sea

The UN Law of the Sea Treaty, or UNCLOS, contains several important innovations for ocean law. It establishes a 12-nautical-mile maximum limit that coastal nations may set for their territorial sea. It defines the continental shelf's limit as the outer edge of the continental margin or 200 nautical miles from the coast, whichever is further seaward. It permits the coastal nation to establish Exclusive Economic Zones (EEZs) beyond the territorial sea, extending up to 200 nautical miles from the coast. While no definition of "high seas" is specified, the UNCLOS provides that all rules regarding the high seas should apply seaward of the EEZ.

Special regimes also are created for marine

Antarctica: Claims and Jurisdictions in the Southern Ocean



Legend:

200 Nautical Mile Zones

Ice Shelves

scientific research, environmental protection, resource management and conservation, and islands. Perhaps most controversial, provision is made for an International Seabed Authority to regulate exploration and exploitation of the ocean floor "beyond the limits of national jurisdiction."

While neither Antarctica nor the Southern Ocean were of particular concern to the negotiators at the time, provisions in the UNCLOS plainly hold important implications for the contemporary situation in the Antarctic, and the multinational regime currently overseeing affairs in the region. There is, however, a weak link in connecting the newer Law of the Sea to the previously existing Antarctic Treaty System.

Territorial Limits

The Antarctic Treaty makes no mention of zones of offshore jurisdiction. The relevance of applying

certain aspects of the new Law of the Sea to the Antarctic thus hinges on the legal status of the continent. No sovereign country exists on the continent, and claims made to Antarctic territory are not the equivalent of independent statehood. Moreover, the Antarctic Treaty does not purport to set up sovereign supervision of the continent and its circumpolar waters. As a consequence, it seems highly doubtful whether Antarctica today could qualify as a condominium,* or a continent of sovereign states. Assuming no coastal nations exist in Antarctica, it is not possible to project the principle of territoriality seaward from the continent. As a result, no territorial seas or Exclusive Economic Zones contiguous to Antarctica would seem permissible.

The continental shelf regime in Antarctica also presents a problematic legal situation. The 1958 Convention on the Continental Shelf maintains that "[t]he coastal state exercises over the continental shelf sovereign rights for the purpose of exploring it and exploiting its resources." Similarly, the UNCLOS allows the coastal nation to obtain sovereign rights over natural resources of the seabed and subsoil of the continental shelf, as well as the exclusive right to undertake or authorize exploration or exploitation ventures. The coastal nation also is mandated to set environmental standards for all activities and installations within its continental shelf jurisdiction.

But, what happens in the event that a coastal nation legally does not exist in the territory? Given the situation in Antarctica, who should have jurisdiction over, and thereby profit from, the use of living and nonliving resources on and in the continental shelf? Who should be responsible for insuring the environmental integrity of the shelf? The new Law of the Sea fails to provide satisfactory answers for the Antarctic situation.

A partial solution may be in a new treaty for managing minerals activities on and around the continent—presently being negotiated (page 20). Included within this draft minerals convention's scope is the Antarctic continental shelf, which lies wholly within the proposed area of application.

If mineral mining is to take place on the Antarctic continental shelf, however, who will profit? Even the Antarctic Treaty fosters ambiguity. Article IV of the treaty froze the existing claims (thus, at least allowing for "ownership" of portions of the shelf), while Article VI allows for the exercising of "high seas" rights by any country.

The claimant countries argue that the right to extend their territorial jurisdiction seaward, like the claims themselves, is protected by the treaty. Nothing in the treaty impugns the claimants' right to assert jurisdiction offshore. The sector lines used to delimit various Antarctic claims do not stop at the continent's edge. Instead, they extend far out into the ocean, and, with the exception of Norway's, end at the 50 degree and 60 degree South latitude line (see map on page 23). Importantly, no legal significance pertaining to jurisdiction has ever been attached to, or publicly suggested about, the sector lines by claimant states.

Nonclaimants, on the contrary, do not recognize these claims. They contend that the absence of a coastal nation means that no jurisdictional zones exist offshore of the continent. Under this argument, under international law, Antarctica's circumpolar waters should be regarded as high seas areas that extend right up to the ice shelves and the continent's shoreline. All states would then possess traditional high seas freedoms in the Southern Ocean, including rights of free navigation, overflight, laying of pipelines and cables, fishing, and scientific research. The chief qualifications on these rights would be the duty to conserve and protect living resources in the region.

Environmental Protection

The Antarctic marine ecosystem is both relatively simple and delicate. It is directly dependent on krill (the shrimp-like animal characteristic of the Southern Ocean) for sustaining the balance of nature in the local food chains. Consequently, preservation and protection of the Southern Ocean's environment is a prominent concern among the ATCP states, and the new Law of the Sea serves that end well. The UNCLOS obligates countries to restrain and control use of pollution-causing technologies in the marine environment, which of course would include Antarctic seas. Countries moreover are enjoined by the UNCLOS to prevent, reduce, and control maritime pollution, regardless of whether it is land-based, seabed-based, vessel-source, dumping-source, or atmospheric in its origin.

The primary responsibility for monitoring and assessing pollution in Antarctic waters presumably would accrue to the International Maritime Organization, referred to in the UNCLOS as the "competent international organization." Other relevant ocean law measures for protecting the Antarctic marine environment are the various international conventions designed to prevent pollution of the high seas by oil. Their scope of application clearly includes the Southern Ocean.

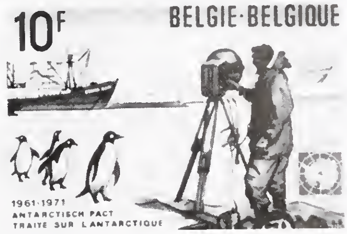
Concern over harm to the marine environment associated with possible minerals development on and offshore Antarctica prompted the ATCPs to include various procedural safeguards in the new minerals treaty. These protective measures have not satisfied environmental groups, however. Greenpeace and the Antarctic and Southern Ocean Coalition (a coalition of environmental groups based in Sydney, Australia) are still quick to criticize the relatively narrow scope and limited application of environmental provisions when compared to the perceived priority given exploration and exploitation opportunities in the treaty. No doubt international legal measures for protecting the Antarctic marine environment will continue to evolve as particular needs become more apparent.

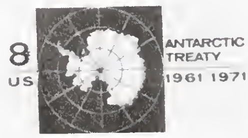
Resource Management and Conservation

The Antarctic continent is practically devoid of indigenous (native to the region) life. By contrast, its circumpolar waters teem with abundant living

* In the geopolitical context, joint sovereignty or rule by two or more nations over a colony or politically dependent territory, as in the Anglo-Egyptian Sudan.

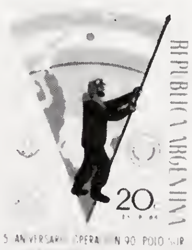
Antarctic Treaty

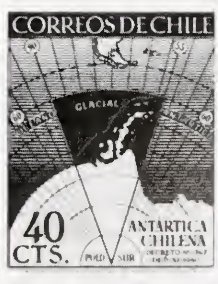




Antarctic National Claims

All stamps in this issue from U.S. Coast Guard Commander Lawson Brigham's collection.





resources. Seals, whales, finfish, squid, and seabirds (particularly penguins) are found in significant numbers. Most attention in recent years has been focused on krill, which swarm along the southeastern waters of Antarctica, as well as around several archipelagoes to the north (see also page 75). Though prospects for a commercial harvest of krill presently are not bright, the huge quantity of krill believed available in the Southern Ocean implicitly holds promise for supplementing the world's growing protein needs. This realization was an important stimulus for the ATCPs to negotiate the CCAMLR.

The basic intent of CCAMLR is to manage and monitor fishing by nations in the region. An "ecosystemic approach" serves as the harvesting guideline for fishermen, and a special institution, the CCAMLR Commission, was created to coordinate scientific advice with resource management policies in the Antarctic. CCAMLR does not restrict the high seas right contained in the UNCLOS to fish in the region. Rather, it reinforces the duty to conserve living resources in the course of exercising that right. UNCLOS obligates fishing states in the Southern Ocean to use the "best scientific evidence available" to ensure that a maximum sustainable yield be maintained for all harvested species.

Regarding nonliving resources, the mineral wealth of Antarctica is unknown. Trace amounts of many metals (for example, gold, silver, tin, cobalt, uranium, and platinum) have been found, but none in any notable quantity. Some interest has been expressed in the potential of oil and gas resources on the Antarctic continental shelf (see also page 32). Yet, no appreciable evidence has been made public so far to suggest that substantial hydrocarbon deposits are present on or offshore the continent. Nevertheless, should continental shelf exploitation of oil and gas in the Antarctic ever come about, it very likely will be regulated by the new minerals regime, rather than the provisions in the UNCLOS. The lack of a sovereign coastal nation on Antarctica would seem to preclude the relevance of UNCLOS, unless the circumpolar continental shelf came to be regarded as a legal projection of the deep seabed under the high seas. In that case, it would fall under the regulatory scope of the International Seabed Authority set out in the UNCLOS.

Deep Seabed Mining

In the UNCLOS, the "international seabed area" comprises the seabed and subsoil beyond the limits of national jurisdiction. This means the area beyond the limits of the continental shelf subject to coastal nation jurisdiction. This deep seabed area under the UNCLOS is declared to be "the common heritage of mankind." No claim, appropriation, or exercise of national sovereignty is permitted over the seabed area or its resources, the principal one of which is polymetallic nodules.

To regulate and manage exploration and exploitation activities in the area, the UNCLOS created the International Seabed Authority (the Authority). The leading question here is, where do the international rights and duties of the Authority end, and those of the Antarctic Treaty System for exploiting minerals on the deep seabed plains around the continent of Antarctica begin?

Though not yet fully resolved, the ATCPs (operating under the Antarctic Treaty System) have attempted to offset potential jurisdictional conflict with the Authority (operating under UNCLOS) over the deep seabed. The new Antarctic Minerals Convention "will apply to Antarctic mineral resource activities which take place on the continent of Antarctica and all Antarctic islands, including all ice shelves, south of 60 degrees South latitude, and the seabed and sub-soil of adjacent offshore areas; . . . [S]uch areas do not include the deep seabed . . . seaward of the [continental] margin adjacent to the relevant land area, or more than 200 nautical miles from its coast. . . ." The clear intent by the ATCPs in fashioning this provision was to establish limits of jurisdiction over the circumpolar seabed similar to those limits set out in the UNCLOS for coastal states over their continental shelves.

At this time, neither the minerals treaty nor UNCLOS is in force, and the issue of conflict remains academic. Should both treaties eventually come into force, however, jurisdictional questions over the rights of parties to mine minerals on the ocean floor seem more likely to become pressing international juridical concerns.

Marine Scientific Research

The Antarctic Treaty is conspicuously noteworthy for promoting international cooperation in free scientific investigation among the "contracting parties" (that is, the ATCPs). Under UNCLOS, the language is similar, but has broader applicability. Here, for parties and nonparties alike, legal restrictions for conducting marine scientific research in Antarctic waters are supplied by Part XIII of the UNCLOS. Countries and "other competent international organizations" are permitted to conduct such scientific research, so long as it is carried out for peaceful purposes and does not interfere with "other legitimate uses of the sea." The UNCLOS also gives all countries the legal right to conduct scientific research on the local deep seabed and in the water column beyond the limits of national jurisdiction.

Because EEZs cannot exist in the absence of a sovereign coastal nation, the logical inference would permit scientific research without consent up to the edge of Antarctica's continental land (ice) mass. Research installations and related facilities in Antarctic waters are allowed. They cannot, however, generate territorial jurisdictional limits, be construed legally as islands, or obstruct international shipping lanes in Antarctic waters.

Islands

A number of islands in the Southern Ocean hold particular significance for Antarctica and the law of the sea—and may serve as tests for sovereignty versus high seas claims. Included among these island groups are Macquarie Island (Australia); Peter I Island (Norway); the South Shetlands (Argentina, Chile, and Britain); South Georgia Island (Argentina and Britain); the South Orkneys (Argentina and Britain); the South Sandwich group (Argentina and Britain); Bouvet Island (Norway); Prince Edward Island (South Africa);

Crozet Island (France); Kerguelen Island (France); and Heard and McDonald Islands (Australia).

While titles to some are disputed, all these land formations qualify as islands under the UNCLOS. Accordingly, each is legally capable of generating a territorial sea, contiguous zone, Exclusive Economic Zone, and continental shelf delimitation. Around some of these island groups, in particular the South Shetlands, South Orkneys, South Sandwich group, South Georgia Island, and Bouvet Island, are impressive krill concentrations. Declaration of 200-nautical-mile EEZs around these islands consequently envelops substantial krill resources, in effect nationalizing them for appropriation by the islands' respective claimant/possessor country. Perhaps because of the resources involved, as well as the legal precedent, declarations by France in 1978 of EEZs around Crozet and Kerguelen Islands, and by Australia in 1979 of 200-nautical-mile fishery zones around Heard and McDonald Islands have been largely ignored by the international community, albeit the lawfulness of these zones has not yet been formally challenged.

Accommodation by Two Systems

The oceans adjacent to the Antarctic continent fall under two distinct international legal systems. Accommodation will not always be easy, and there has been some criticism.

The Antarctic Treaty System presently administering activities in the Southern Ocean takes Law of the Sea considerations into account when negotiating policies affecting national activities in the region. The relatively confined ATCP process, however, especially as it regards resource management in the Antarctic, has not escaped international criticism. Primarily because only a select few countries have gained ATCP status thus far, nonparty states, such as Malaysia, Antigua and Barbuda, and Sierra Leone, have been quick to find fault in the system. Not surprisingly, these governments have exclaimed their preference for creating a "common heritage of mankind" regime to govern the Antarctic.

The likelihood of such a new regime coming about in the foreseeable future seems dim, especially considering the ATCPs' opposition to the proposal on grounds of the substantial financial, scientific, and legal commitments already invested by ATCPs in Antarctic activities during the last three decades.

The Antarctic Treaty System and the UN Convention on the Law of the Sea together supply an appropriate legal framework for prudent resource management, conservation, and protection of the Antarctic marine environment. Nonetheless, both these legal regimes must continue to evolve in scope and content so as to permit ocean law in the Antarctic to keep pace with new demands imposed by technology and global resource needs.

For international interests to be best served in the Antarctic, the current Antarctic Treaty System must become suitably accommodated with the new Law of the Sea. This need is especially apparent as ocean law emerges through national practice during the coming decades.

The prospects for the Law of the Sea becoming even more integral to the management of Antarctic maritime activities look good. This trend plainly is encouraging. In the contemporary era of increasing competition for scarce resources and exaggerated ideological priorities, such an opportunity for international cooperation certainly should not be lost.

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Selected Readings

Auburn, F. M. 1982. *Antarctic Law and Politics*. Bloomington: Indiana University Press.

Joyner, C. 1988. The evolving Antarctic minerals regime. *Ocean Development and International Law* 19(1): 73–96.

Joyner, C. 1987. The Antarctic minerals negotiating process. *American Journal of International Law* 81(4): 888–905.

Joyner, C. 1984. Ocean pollution and the Southern Ocean: Rethinking the international legal implications for Antarctica. *Natural Resources Journal* 24: 1–40.

Joyner, C., and S. Chopra, eds. 1988. *The Antarctic Legal Regime*. The Hague, Netherlands: Martinus Nijhoff.

Oxman, B. 1986. Antarctica and the new law of the sea. *Cornell International Law Journal* 19(2): 211–248.

Triggs, G., ed. 1987. *The Antarctic Treaty Regime*. Cambridge, England: Cambridge University Press.

A Brief History of Antarctica

500 BC Greek philosophers argue that the Earth is a sphere: geographers fill this new world with imaginary lands and seas; their belief in symmetry leads to concept of a southern landmass, *Terra Australis Incognita*, to balance the known northern lands.

1772 Yves Joseph de Kerguélen-Trémarec (French): discovers a group of ice-bound islands in southern Indian Ocean, but unable to land because of fog and ice conditions; fabricates reports of rich land where ". . . wood, minerals, diamonds, [and] rubies will be found"; is sent back in 1774 to colonize and establish trade with natives, but finds land inhospitable; court-martialled on return to France.

1772–75 Captain James Cook (British): is first to cross Antarctic Circle; goes as far south as 71 degrees 10 minutes South latitude, but never sees continent; dispels myth of rich and temperate *Terra Australis*; reports abundance of seals and whales.

1790 Fur sealers (British and American) begin hunting in Antarctic waters: fur seal population decimated by 1830.

1820 Three countries claim to be first to sight continent: Britain—Edward Bransfield, naval officer; Russia—Thaddeus von Bellingshausen (though he does not claim to have seen it himself); United States—Nathaniel Palmer, a sealing captain.

1819–21 Bellingshausen expedition (Russian): circumnavigates continent in two seasons; discovers Peter I Island and Alexander Island; ship reinforced with copper-plated bottom.

1821 Captain John Davis (American): first to set foot on continent, on Antarctic Peninsula.

1823 James Weddell (British sealer): penetrates far into pack ice and discovers Weddell Sea; sets record of 74 degrees 15 minutes South latitude.

1837–40 Jules-Sebastien C. Dumont d'Urville (French): claims part of continent for France (names it Adélie Land for his wife); takes back thousands of natural history specimens.

1838–42 Charles Wilkes (American): leads large, poorly organized expedition; upon his return, he is court-martialled by U.S. Navy for poor conduct as Commander, but awarded gold medal by the Royal Geographic Society for exploration.

1839–43 James C. Ross (British): leads expedition to find South Magnetic Pole (had discovered North Magnetic Pole in 1831); discovers Ross Sea, Ross Ice Shelf, Transantarctic Mountains, and two volcanoes (one active); sets new southward record, going past 78 degrees South latitude; Joseph Hooker, a scientist signed onto expedition as a surgeon, makes vast plant collection.

1874 Captain George S. Nare (British): commands *HMS Challenger*; first steam vessel to cross Antarctic Circle; collects rocks dredged from ocean bed, which were later shown to be of continental, not island, origin.

1892 Carl A. Larsen (Norwegian) (see 1904): lands on island near tip of Antarctic Peninsula; discovers first fossils—petrified wood—pointing toward a warmer past.

1894 Bull-Kristensen expedition (Norwegian): first to set foot on mainland, outside of Antarctic Peninsula; find lichen, first sign of plant life.

1895 Sixth International Geographical Congress in London: resolves that "the exploration of the Antarctic region is the greatest piece of geographical exploration still to be undertaken"; launches era of government-sponsored national expeditions.

1898 Adrien de Gerlache de Gomery (Belgian): ship drifts in pack ice for 12 months, making it first ship to winter in the Antarctic; Roald Amundsen (see 1910) is a member of the expedition.

1898–1900 Carsten E. Borchgrevink (Norwegian): first expedition to winter on land; zoologist, Nicolai Hanson, dies; first Antarctic burial.

1901–03 Erich von Drygalski (German): leads official German expedition; meteorologists on board observe the abrupt sinking of "ice water" below water along the line now called the Antarctic Convergence; ship held in ice for 12 months, crew had to stoke ship's furnace with penguins (penguin blubber burns well!).

1901–03 Otto G. Nordenskjöld (Swedish): ship crushed in ice in Weddell Sea; crew winters in three separate parties until rescued by Argentine Navy.

1901–03 Robert F. Scott (British) (see 1910–12): leads the Discovery Expedition; the ship, *Discovery*, is built expressly for navigation in sea ice; first extensive scientific expedition to continent; makes first serious attempt to reach South Pole, reaching 82 degrees 15 minutes South latitude; performs aerial surveys from captive balloon, from which Ernest Shackleton (see 1908 and 1914) takes photographs.

1902–04 William S. Bruce (Scottish): first oceanographic exploration of Weddell Sea; sets up meteorological observatory in South Orkney Islands.

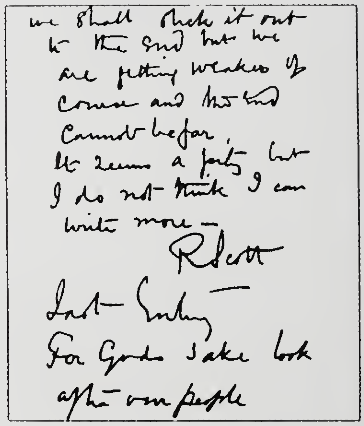
1904 Birth of modern Antarctic whaling: Carl A. Larsen (Norwegian) establishes shore-based station on South Georgia.

1908 Ernest Shackleton (British) sleds to 88 degrees 23 minutes South, 97 miles from the South Pole.

1909 T. W. Edgeworth David (Australian): reaches South Magnetic Pole, which was then at 72 degrees 25 minutes South, 115 degrees 16 minutes East.

1909 Robert Peary (American): reaches North Pole (90 degrees North), leaving South Pole (90 degrees South) as the Earth's "last geographical prize."

1910–12 Robert F. Scott (British) and Roald Amundsen (Norwegian) race to be first at the South Pole; Scott sets out for Antarctica intending scientific studies as well as first trek to South Pole; while enroute, Scott receives telegram from Amundsen, "Beg to inform you proceeding to Antarctica"; Amundsen's team of five men has 4 sleds and 52 dogs, which can be killed and used for food; has good trip with fairly good weather; Scott has no faith in dog teams, chooses to ski to pole; Scott's party of 14 men moves slowly because of bad weather, rough terrain, and exhaustion; 14 December 1911, Amundsen reaches pole; Scott reaches pole 18 January 1912, finding Norwegian tent, flag, and letters; on trip back, weather very foul, supplies dwindling, all four men in Scott's party die by March 1912; bodies not found until November 1912, as well as diary left by Scott. Last entry:



1914 Shackleton aims to cross Antarctic by land; ship is crushed in ice; crew camps on floating ice until it drifts to an island; eventually rescued by Chilean vessel in 1916.

1917–40 Countries start laying claims to various regions on Antarctic mainland and adjacent islands: 1908, Britain; 1923, New Zealand; 1924, France; 1925, Argentina; 1931, Australia; 1939, Norway; 1940, Chile.

1923 British Discovery Committee founded: first real effort at sustained research in the Antarctic; 13 separate cruises made between 1925 and 1939.

1928 Sir Hubert Wilkins (British): introduces first aircraft, allowing aerial surveys; fails in two attempts to fly across continent, but takes remarkable aerial photos.

1928–38 Norwegian ships and aircraft explore coastline and interior of Enderby Land and Dronning Maud Land: later planes from Hitler's Germany survey area and symbolically stake claim to Antarctica by dropping thousands of metal darts engraved with swastikas.

1929 Richard E. Byrd (American): first flight over the South Pole (see also 1946–47 entry).

1935 Mrs. Mikkelson (Norwegian), wife of whaling captain: first woman to land on continent.

1935 Lincoln Ellsworth (American): first successful trans-Antarctic flight.

1946–47 Byrd leads Operation Highjump: organized by U.S. Navy, is most ambitious exploratory venture; 13 ships, 23 aircraft, 4,700 men.

1949–52 Norwegian-British-Swedish Expedition: first truly international Antarctic expedition; first seismic traverse of inland ice-sheet.

1950 Third Polar Year recommended for period 1957–58: will be called the International Geophysical Year (IGY): Antarctica will be main area of study.

1954 Australian Antarctic Research Expeditions (ANARE) establishes Mawson base: first, large, permanent scientific base.

1955 Four U.S. Navy heavy cargo airplanes fly from New Zealand to Antarctica, thus linking Antarctica directly to rest of world for the first time.

1957 United States builds Amundsen-Scott Station at South Pole.

1957 International Council of Scientific Unions (ICSU) establishes the Scientific Committee on Antarctic Research (SCAR): SCAR to organize international research after the IGY.

1957 IGY begins: more than 33,000 scientists from 67 nations manning more than 1,000 stations (not only in Antarctica, but around the world); the research includes stratospheric studies, transcontinental traverses, and seismic studies.

1958–59 Soviets set up observation stations at the South Geomagnetic Pole and the Pole of Inaccessibility (the furthest point from all Antarctic coasts).

1959 Antarctic Treaty signed: ratified in 1961.

1973 David Lewis (New Zealand): completes first solo voyage to Antarctica in 33-foot steel sloop, *Ice Bird*.

1978 Emilio de Palma (Argentine): first person to be born in Antarctica.

1979 An Air New Zealand DC-10 carrying 257 tourists over Antarctica crashes into Mt. Erebus: no survivors.

1980 Signing of the Convention for the Conservation of Antarctic Marine Living Resources (CCAMLR).

1980 Biological Investigations of Marine Antarctic Systems and Stocks (BIOMASS) created by SCAR: three international biological oceanographic expeditions between 1980 and 1985.

1982 As part of the Falkland Islands War, an Argentine ship arrives at South Georgia, reviving a territorial feud begun in 1925; after short battle, they take the island from a British garrison; a British force recaptures it 3 weeks later.

1988 U.S. successfully restores and flies LC-130 cargo plane buried in ice for 16 years, but loses another aircraft, with loss of life, in the process.

1988 Minerals regime adopted.

—SLE

Antarctica:

Is There Any Oil and Natural Gas?

by David H. Elliot

Heavy hydrocarbon residues have been found in a sediment core recovered in McMurdo Sound. This event was reported last year by geologist Peter Barrett, Director of the Antarctic Research Centre at Victoria University, Wellington, New Zealand.

These residues show that liquid hydrocarbons have migrated up and laterally through the rock sequence, and have probably escaped to the ocean floor. There they are dispersed by wind, waves and currents, and degraded by biological activity, in the same way as oil seeps are dispersed and degraded elsewhere in the world, for example in offshore southern California. The residues may suggest to some that hydrocarbon accumulations are present, although they by no means indicate the size of any accumulation. What hard evidence can be brought to bear on this question?

Antarctic Geology

The continent of Antarctica is 98 percent covered by snow and ice, nevertheless, the broad outlines of the geology are well established. Geologically, the Antarctic continent is composed of two distinct provinces—the older, more quiescent, and larger East Antarctica; and the younger, more active West Antarctica, which includes the Antarctic Peninsula (Figure 1).

From the scattered rock outcrops along the periphery of the continent, and the intracontinental mountain ranges like the Transantarctic Mountains, geologists have concluded that East Antarctica is made up of ancient crustal rocks like those found in western Australia, peninsular India, and southern Africa. Along the Transantarctic Mountains, these ancient rocks merge into a belt of younger and less-intensely deformed and heated sedimentary and volcanic rocks, together with granite intrusions. During the Early Paleozoic, about 450 million years ago, this belt was eroded down to a surface of low relief on which sedimentary rocks were deposited for much of the following 300 million years.

Coal seams discovered in the Transantarctic Mountains during IGY. (Photo courtesy of the British Antarctic Survey)

West Antarctica and the Antarctic Peninsula, with few exceptions, lack the ancient rocks that characterize East Antarctica. Instead, their geology is dominated by granites, sedimentary, and volcanic rocks that are younger than about 500 million years. Late Cenozoic (less than 25 million year old) volcanic activity is widespread on the Antarctic Peninsula, West Antarctica, and the Ross Sea sector of the Transantarctic Mountains; and active or recently active volcanoes occur in all those areas. Except for the Antarctic Peninsula, none of the exposed rock provides direct evidence for the existence of marine sedimentary basins. Indirect evidence, however, points to their presence.

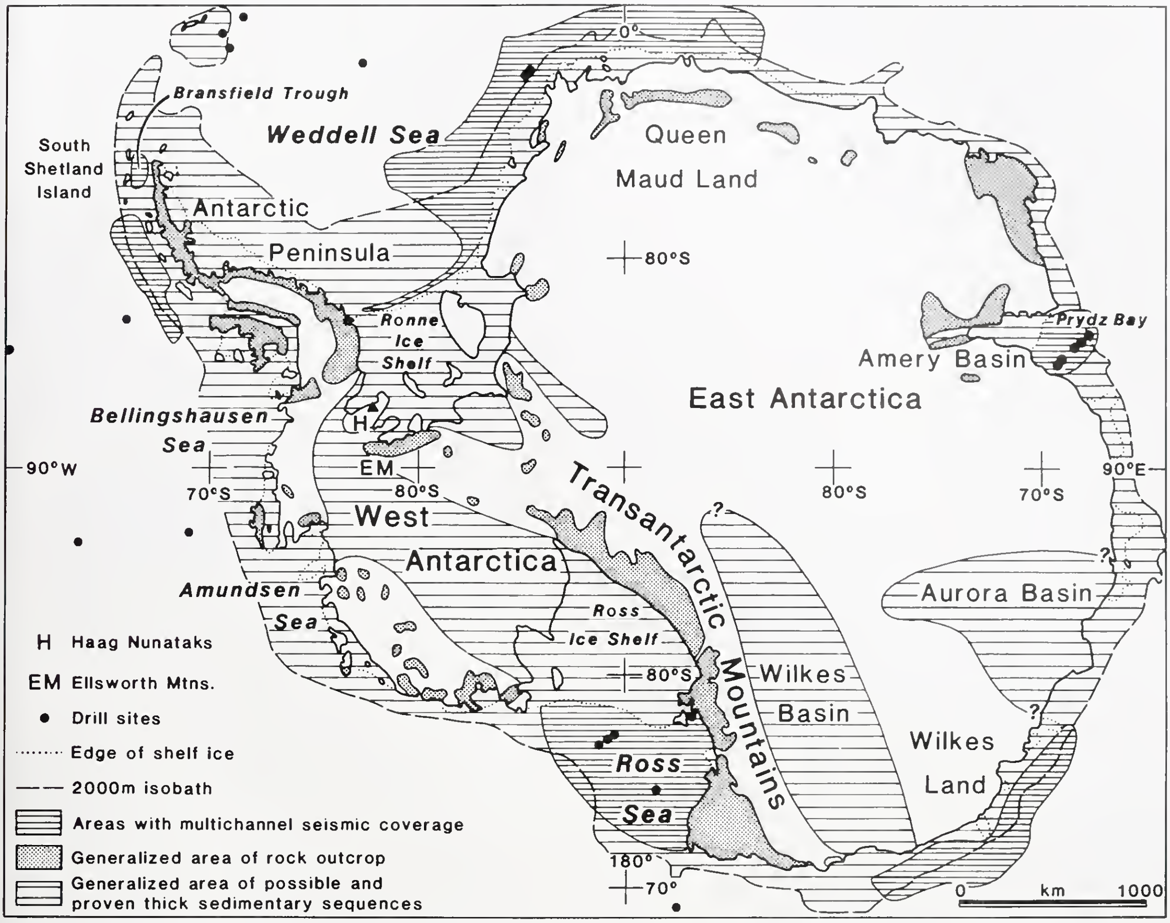


Figure 1. Sedimentary basins are located on the continental margin of Antarctica and in the interior of West Antarctica. Sediments also probably occur other places inland of the East Antarctic ice margin, and certainly are present seaward of the 2,000-meter bathymetric contour. The only regions for which adequate seismic data exist to establish sediment thicknesses and the broad outlines of the basins are the Ross Sea, part of the Wilkes Land coast, Prydz Bay, the western margin of Queen Maud Land and along the immediate front of the Ronne and Filchner Ice Shelves, and parts of the continental shelf west of the Antarctic Peninsula. Information is sparse for interior West Antarctica, very poor for the Wilkes and Aurora Basins, and nonexistent for much of the continental margin—including the Amundsen and Bellingshausen Seas. The sediments recovered at the drill sites on the continental shelf provide some age control for the stratigraphy developed on the basis of seismic data.

For petroleum geologists, these marine sedimentary basins are of primary interest. The major Antarctic basins lie on the continental shelves, and in the Ross and Weddell embayments of West Antarctica. These basins all postdate the breakup of Gondwanaland (see page 8), the ancient supercontinent formed of all the southern continents and peninsular India. Antarctica formed the hub of the supercontinent for the hundreds of millions of years that it existed. For much of that time, Antarctica enjoyed a more agreeable climate; vegetation was abundant and reptiles roamed the landscape. The fragmentation of Gondwanaland began about 150 to 160 million years ago. The youngest and final split was initiated about 28 million years ago, and completed the physical isolation of the Antarctic continent.

Except for the Antarctic Peninsula, most of the geologic history of the continent for the last 150 million years is held in the marine sedimentary basins. To understand the history and evolution of the basins, seismic surveys and drilling projects have been conducted. The academic interest in the basins is paralleled by interest in their potential for hydrocarbon resources.

Sources and Traps for Hydrocarbons

Hydrocarbons are generated from marine and terrestrial organic debris—in general, the marine debris yields oil, and the terrestrial debris yields gas. The amount of organic matter in sediments tends to decrease with increasing grain size, so that mudstones and claystones will be better source rocks for hydrocarbons than sandstones.

The organic matter is broken down to yield oil and gas by a combination of temperature and time. With increasing depth of burial of the source rocks by younger sediments, the temperature rises; the actual temperature attained at any particular time, however, depends on the heat flow from the Earth's

interior, and this is altered by such things as the rate of burial and magmatic activity, in other words, volcanism.

Assuming the source rocks pass through the time-temperature window for hydrocarbon generation, oil and gas will be produced and will migrate away, both laterally and vertically. The hydrocarbons may accumulate in those rocks that contain voids, such as some limestones, or more commonly, porous sandstones. The reservoirs in which the hydrocarbons accumulate must be sealed by a "cap rock" so that oil and gas do not escape. The seals are commonly impermeable clay-rich beds, but in addition, the form of the reservoir and its seal has to be such that the hydrocarbons can accumulate as pools. Various geologic structures can provide a suitable setting. One example would be a reservoir and its cap in the form of a low dome. Another example would be an anticline, an elongate structure with an arch-like form—the prolific producing fields in Saudi Arabia are like this (Figure 2).

Many marine sediments contain organic matter at the time of deposition, and methane is commonly generated both at the sea floor and with subsequent burial. However, the presence of methane in a drill core cannot be taken as an automatic indicator of oil and natural gas. Oil seeps, on the other hand, provide a sure indication that hydrocarbon generation has occurred, but they do not necessarily mean large accumulations are present.

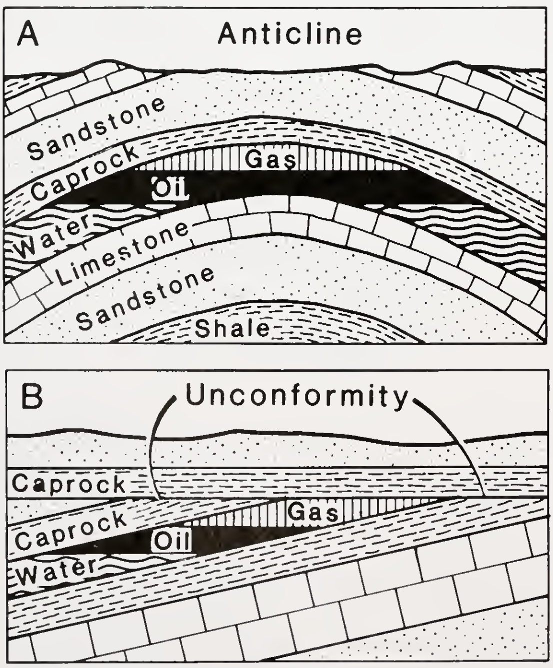


Figure 2. Oil and natural gas collect in porous sandstones and other rocks with voids. But for their accumulation, there must be an impermeable cap rock to prevent their escape, and a suitable structure to contain the pool of hydrocarbons. An anticline, or arch-like structure, is illustrated in A. B illustrates an unconformity, which in this case would be the result of deformation and tilting of rocks, their erosion to a near horizontal surface, and the subsequent deposition of sedimentary rocks on top of the erosion surface. Both of the illustrated settings are referred to as structural traps. Other types of traps occur.

The assessment of the nature and sequence of sedimentary rocks in a basin is best done by seismic exploration, particularly when linked to rock outcrops and regional geology. The succession of beds distinguished by seismic properties is commonly referred to as acoustic stratigraphy. The seismic data can also delineate structures that may be favorable for hydrocarbon accumulation. The Prudhoe Bay field on the north slope of Alaska, a super-giant field with more than 9 billion barrels of oil, measures only a few tens of kilometers on a side, and points to the need for close spacing of seismic lines to identify possible structures for trapping hydrocarbons. Only drilling and core recovery can establish ages for the acoustic stratigraphy, and, as a final test, prove the existence of any accumulations.

The many factors involved in the generation, migration, and accumulation of hydrocarbons make oil and gas fields the exception rather than the rule. Nevertheless, the only continent without any known major hydrocarbon accumulations is Antarctica. Any potential for oil and natural gas lies in the sedimentary basins.

The Ross Embayment

The Ross Sea region is divided into the Victoria Land Basin and two less well-defined basins lying east of about 170 degrees East (Figure 3). The structure and sediment thickness in the Victoria Land Basin are comparatively well known, largely as a result of recent work by Alan K. Cooper of the U.S. Geological Survey, Menlo Park, California, and others. As much as 14 kilometers of sediment are present. Marine microfossils (from small single-celled organisms), principally diatoms and foraminifera, reworked into glacial and other deposits found in the McMurdo Sound region demonstrate that marine beds as old as late Cretaceous (80 million years ago) are present somewhere beneath the ice in the Ross embayment. The geology of the basin was formed by alternating periods of rifting and basin filling.

The site from which the heavy hydrocarbon residues were recovered lies on the western margin of the Victoria Land Basin. The residues occur near the base of a 700-meter-thick sequence of glacial and nonglacial marine sediments that range in age from 38 million years to modern time. The source of the hydrocarbons is unknown. It also is unknown whether any hydrocarbons are trapped anywhere in the basin.

Two basins, the Central Trough and the Eastern Basin, lie to the east of the Victoria Land Basin. Both have as much as 6 kilometers of sediment fill. The Central Trough is about 50 kilometers wide and is probably rift-related, whereas the Eastern Basin is broad and mainly the result of simple subsidence.

The western margin of the Eastern Basin was sampled at three sites that were drilled by the now-retired *Glomar Challenger*, the drilling vessel operated by the old Deep Sea Drilling Project (DSDP). Gaseous hydrocarbons were detected in cores from DSDP Sites 271, 272, and 273. Most

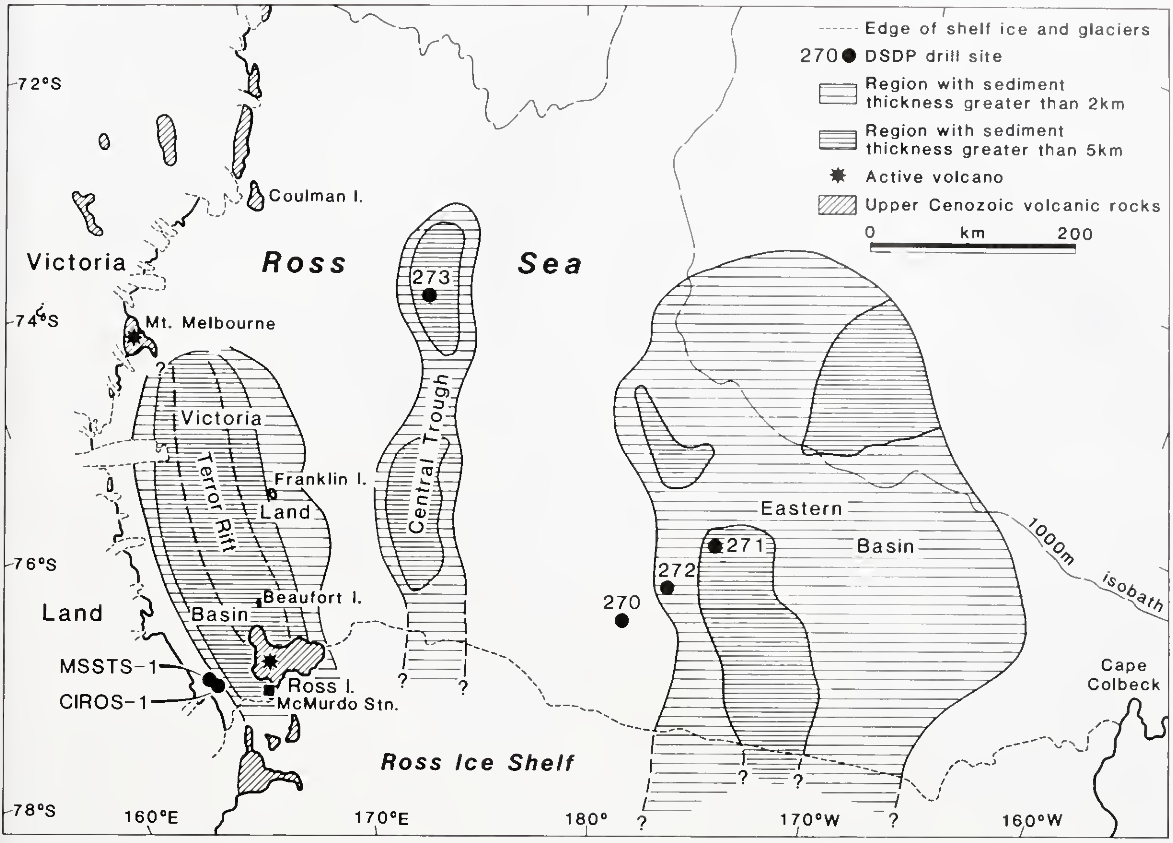


Figure 3. The sedimentary basins on the Ross Sea continental shelf are the best defined of all basins in Antarctica. Multichannel seismic lines have been run by the U.S. Geological Survey, the West German Geological Survey, the French National Petroleum Institute, the Japanese National Oil Company, the Soviet Antarctic Expedition, and the Italian Experimental Geophysical Observatory. Drilling also has been conducted by the Deep Sea Drilling Project (DSDP) and the New Zealand Antarctic Research Program (MSSTS-1; CIROS I and II). The Terror Rift in the Victoria Land Basin is the central part of the deep basin. It contains a thick sedimentary sequence and is the site of many submarine volcanoes. The basins extend beneath the Ross Ice Shelf, but data to define them subglacially is lacking.

were methane, but traces of ethane and higher forms also were present. However, they are probably of biological origin and not related to petroleum generation. Calculations by Frederick J. Davey, Chief Geophysicist with the Department of Scientific and Industrial Research, New Zealand, suggest that only the deepest parts of the Eastern Basin and Central Trough could have been in the appropriate time-temperature regime for hydrocarbon generation.

The Weddell Embayment

The Filchner and Ronne Ice Shelf region of the Weddell embayment, like the Ross embayment, possibly contains as much as 14 kilometers of sediment, but the age and nature of the sequence is not known. West Antarctica is regarded as the Early Mesozoic "Pacific" margin of Gondwanaland, which was disrupted by breakup and subsequently thinned by crustal extension. The sediment filling this post-breakup basin is therefore likely to be no older than late Jurassic (about 150 million years ago), and to consist of terrigenous and pelagic sediment overlain by glacial deposits laid down in the last 30 million years.

The Weddell embayment is part of a much larger region of interest that includes the continental margins lying east of the Antarctic Peninsula and west of Queen Maud Land, and together with the Falkland Plateau, share an origin related to Gondwanaland break-up. Claystones and muds with total organic carbon contents of up to 8.6 percent are known from the Falkland Plateau and western Queen Maud Land, and lower contents, up to 3.5 percent, in outcrops on the northern Antarctic Peninsula. Beds rich in organic carbon, often referred to as sapropelic beds, are potential hydrocarbon source rocks.

The presence of such sapropelic beds in the Ronne Ice Shelf region of the Weddell embayment seems probable, and with up to several kilometers of younger strata overlying them, the possibility of hydrocarbon generation seems likely. Whether hydrocarbons were indeed generated, and whether other conditions were suitable for their entrapment, is another matter.

David I. M. Macdonald, a geologist with the British Antarctic Survey, and his colleagues have evaluated the hydrocarbon potential of the Larsen Basin on the east flank of the Antarctic Peninsula,

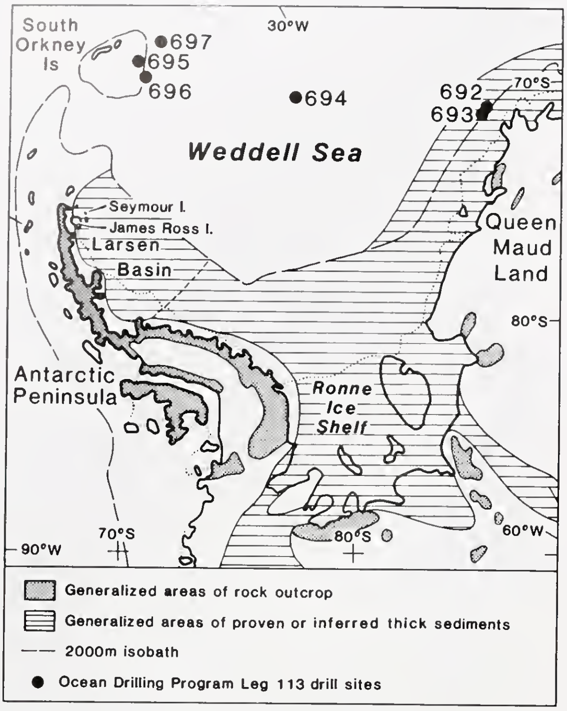


Figure 4. The sapropelic (organic carbon-rich) claystones and mudstones in the northern Antarctic Peninsula, near James Ross Island, and on the western Queen Maud Land margin at ODP sites 692 and 693, could be source rocks for hydrocarbons. Other than for the northwestern margin of the Larsen Basin and the Queen Maud Land margin, information on the sedimentary sequences is extremely sparse.

and speculate that there is moderate potential for hydrocarbons derived from Upper Jurassic and Lower Cretaceous source rocks. The hydrocarbons would be held in reservoirs of Cretaceous and Cenozoic sandstone and conglomerate, and in large structural or stratigraphic traps.

On the other margin of the Weddell Sea, off Queen Maud Land, information about the sequence of sedimentary beds was obtained last year by the Ocean Drilling Program. (The Ocean Drilling Program is the successor to the Deep Sea Drilling Project but uses a newer vessel, the JOIDES *Resolution*.) The drilling recovered mid-Cretaceous (110–100 million-year-old) sapropelic claystones and mudstones (Figure 4). Stratigraphic thicknesses are in excess of 4 kilometers on the continental shelf and in a possible rift basin just off the continental slope. The oil "window" is estimated to lie in the deepest part of the rift basin, and to lie well below the organic-rich beds on the continental shelf. The likelihood of hydrocarbons is slim.

The Antarctic Margin

A number of other basins and sites of interest have been surveyed around the Antarctic margin. A substantial sediment thickness, as much as 14 kilometers, is inferred for the rift in which the Lambert Glacier is situated. This rift, identified on the basis of geophysical data, opens out into Prydz Bay and constitutes the Amery Basin. During January 1988, five sites were drilled in Prydz Bay by Leg 119 of the Ocean Drilling Program. John A. Barron of the U.S. Geological Survey in Menlo Park, California, reports that traces of gas were found at one of the sites. However, it is uncertain whether any significance can be attached to this occurrence because of the relatively shallow depth at which the gas was encountered, and the lack of knowledge of the regional geology.

The Wilkes Land margin is of particular interest because of the probability that an extensive marine basin, the Wilkes Basin, exists inland beneath the ice. Sedimentary beds in the Wilkes Basin are possibly as old as 80 million years, but thicknesses are unknown. On the outer continental shelf, as much as 6 kilometers of sediment are present. Pebbles of organic-rich siltstone of Early Cretaceous age (120–115 million years old) have been found on the seaward flank of a fjord cut into the continental shelf; these pebbles indicate possible hydrocarbon source rocks in the Wilkes Land coastal region.

Other possible sedimentary basins exist along the East Antarctic margin, the west coast of the Antarctic Peninsula, and particularly on the broad continental shelves of the Amundsen and Bellingshausen Seas. Because of their geologic or tectonic setting, these areas offer much less promise than those already discussed.

Finally, hydrocarbons have been reported from the Bransfield Trough adjacent to the South Shetland Islands. These hydrocarbons were found in surface cores taken from a thin sedimentary sequence no older than about 2 million years. The high thermal gradients needed to generate hydrocarbons at such shallow depths and in such young sediments, are a consequence of the tectonic setting, which is a rift regime with associated thin continental crust and active volcanism. The sediments can be considered a present day source rock, but it is unlikely that any stratigraphic or

Table 1. The Geologic Time Scale

Era	Period	Age(m.y.)
Cenozoic	Quaternary	1.6
	Neogene	25
	Paleogene	65
Mesozoic	Cretaceous	145
	Jurassic	210
	Triassic	245
Paleozoic	Permian	285
	Carboniferous	360
	Devonian	410
	Silurian	440
	Ordovician	505
	Cambrian	570
Precambrian		

m.y. = million years

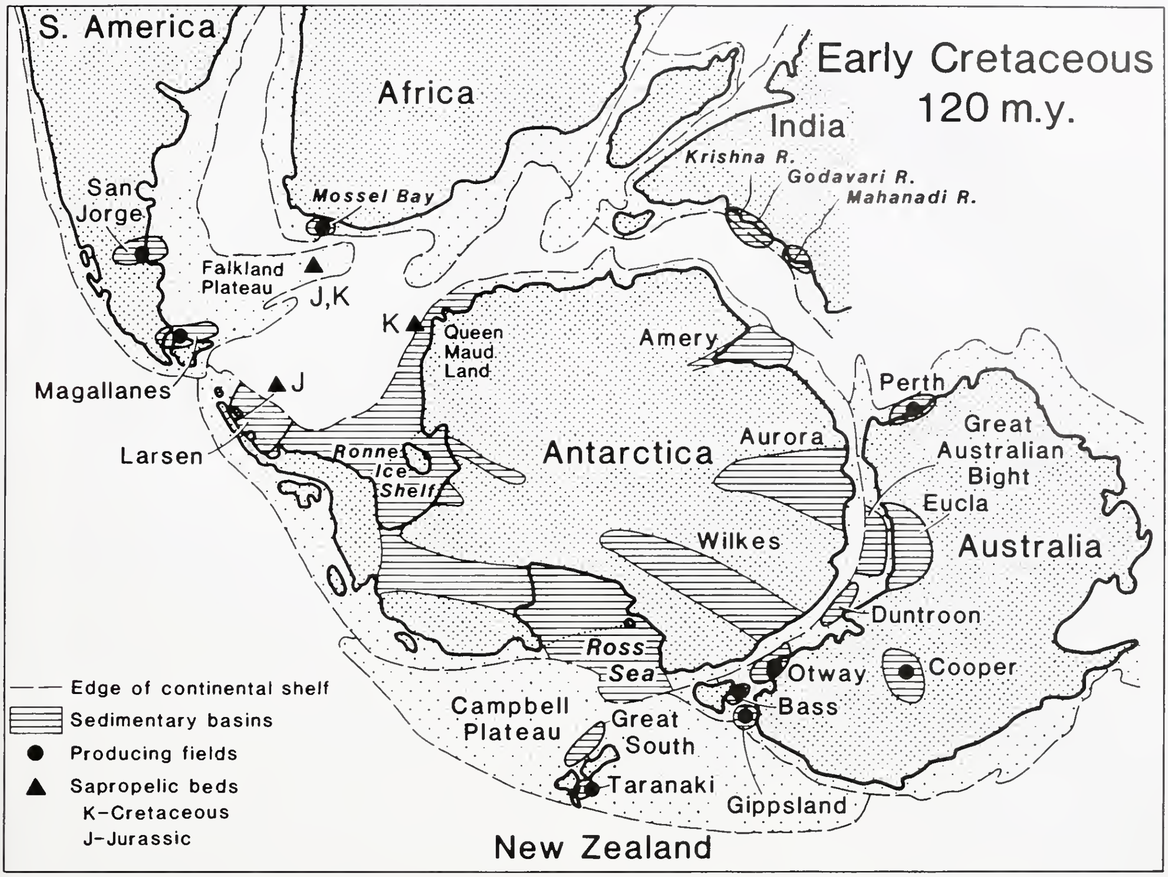


Figure 5. Reconstruction of Gondwanaland in Early Cretaceous time (120 million years ago) shows the proximity of Antarctic basins to basins on formerly adjacent continents, some of which are oil and gas producers. The basins were formed either during the process of rifting of Gondwanaland, or subsequent to that event. The Bass and Otway basins, and that in Mossel Bay, are minor hydrocarbon producers. Subeconomic quantities are present in the Great South Basin and off peninsular India. No hydrocarbons have been reported from the Great Australian Bight, Eucla, or Duntroon basins. It is not clear how many, if any, of the basins on the conjugate margins are analogs for the Antarctic sedimentary basins because of differences in time of formation, sediment thickness, history of deformation, and other factors.

structural traps exist that would retain the hydrocarbons. The hydrocarbons, therefore, are most likely to seep onto the sea floor and be dispersed and degraded by normal marine processes.

Hydrocarbon Assessments

The scale of Antarctic maps commonly over emphasizes the true extent of seismic coverage of the basins. The coverage so far only permits the delineation of the major features of the basins, and with line spacings typically between 50 and 100 kilometers, can at best be considered a reconnaissance of the continental shelf. The lack of detailed information about the sedimentary basins, including the absence of stratigraphic drilling that could provide data on the older parts of the sequences, makes estimates of hydrocarbon potential totally speculative.

Despite these shortcomings in the knowledge of the geology, estimates of the hydrocarbon potential of the Antarctic sedimentary basins have been made. At the optimistic end of the speculation spectrum, Bill St. John, a consultant with Primary Fuels, Inc. in Houston, Texas, has suggested that as much as 203 billion barrels of oil might be present. A conservative estimate by Charles Masters of the U.S. Geological Survey, Washington, D.C., and others, is 19 billion barrels, with only a 5 percent probability of occurrence. (By way of comparison, total domestic U.S. production to date is about 145 billion barrels, and identified reserves amount to 47 billion barrels.)

Models based on averages and probabilities, such as used by St. John, have limitations, and are particularly misleading when taken out of context and divorced from the caveats that are stated by the authors or implicitly understood by geologists. The experience of the search for oil on the Atlantic coastal shelf of the United States, for which orders of magnitude more information was available at the start of exploration, is a cautionary tale. For the billions of dollars spent on exploration and drilling, the only result so far has been the discovery of non-

A frond of the tree fern, Cladophlebis, *preserved in the Cretaceous sandstone of Alexander Island (on the west coast of the Antarctic Peninsula)—a clear indication of Antarctica's location in a much warmer climate 100 million years ago. (Photo courtesy of the British Antarctic Survey)*

commercial amounts of gas in the Baltimore Canyon region.

Analogs on Other Margins

Assessment of hydrocarbon resources includes drawing analogies with hydrocarbon-bearing sedimentary basins, and actual producing fields. In the case of Antarctica, analogies also have been drawn with basins on the formerly adjacent or conjugate margins of the other Gondwanaland continents. Like other methods used to predict the presence of oil and gas, this procedure has its pitfalls. Basins, and even producing basins, on related continental margins are no guarantee of basin and resource sites in the Antarctic. Figure 5 shows several of these sites.

The conjugate margin to the Ross Sea region is the continental shelf around New Zealand. The Taranaki Basin off the North Island is mainly a gas producer, although a major oil discovery has recently been reported. The Taranaki Basin is sometimes cited as an analog, but its development bears only a distant relationship to the evolution of the Antarctic margin.

The Gippsland Basin, in the Bass Strait between Tasmania and Victoria, is a major producer. However, the tectonism controlling the formation of the structures in which the hydrocarbons are trapped has no known parallels in Antarctica—and would not be expected, since at the time of deformation the two continents were geographically separated. The Cooper Basin in central Australia lies in a broad geologic province which possibly extended southward into Wilkes Land prior to breakup 80 million years ago. Hydrocarbons in the Cooper Basin are found in two sedimentary sequences, both of which might possibly occur subglacially in Antarctica.

In southern South America, the San Jorge and Magallanes Basins contain producing fields. Although significant parallels exist with the Larsen Basin of the Antarctic Peninsula, the deformational and thermal histories are likely to differ, and hence the thermal maturation of any organic matter and the subsequent migration of any hydrocarbons.

Much additional information is needed before the significance of any parallels and differences between Antarctica and the conjugate margins can be adequately evaluated.

Doubt

The organic carbon-rich siltstones, mudstones, and claystones known from the Wilkes Land margin, the Queen Maud Land coast, and the Antarctic Peninsula demonstrate the presence of suitable source rocks. Suitable sandstone reservoir rocks seem likely just from general considerations of the known and inferred geologic history. Whether suitable traps are present is more speculative. Furthermore, knowledge of the thermal and tectonic histories of these basins is limited. The reconnaissance nature of most studies, at least in terms of hydrocarbon resource evaluation, makes any assessment subject to great uncertainty. Nevertheless, it would be surprising indeed, if all the Antarctic basins lacked hydrocarbons, and if a few would not be producers—if they were located in more favorable geographic, environmental, and economic settings.

It is difficult to see how anything less than a super-giant field—one with 10 billion barrels of recoverable hydrocarbons—would ever be exploited economically in Antarctica. In their time, however, such reservations were, no doubt, expressed about other frontier areas, including Prudhoe Bay, and the McKenzie River delta on the edge of the Arctic Ocean.

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Selected References

Behrendt, J. C. Scientific studies relevant to the question of Antarctica's petroleum resource potential. In, *Geology of Antarctica*, ed. R. J. Tingey. Oxford England: Oxford University Press. In Press.

Davey, F. J. 1985. The Antarctic margin and its possible hydrocarbon potential. *Tectonophysics* 119: 443–470.

Elliot, D. H. 1985. Physical geography—geological evolution. In, *Key Environments—Antarctica*, eds. W. N. Bonner and D. W. H. Walton, pp. 39–61. Oxford England: Pergamon Press.

Hinz, K., and Y. Kristoffersen. 1987. *Antarctica: Recent advances in the understanding of the continental shelf.* Geologisches Jahrbuch, Reihe E, Heft 27: 54 pp.

Macdonald, D. I. M., P. F. Barker, S. W. Garrett, J. R. Ineson, D. Pirrie, B. C. Storey, A. G. Whitham, R. R. F. Kinghorn, and J. E. A. Marshall. 1988. A preliminary assessment of the hydrocarbon potential of the Larsen Basin, Antarctica. *Marine and Petroleum Geology* 5: 34–53.

The Southern Ocean and Global Climate

by Arnold L. Gordon

If you think of the sea ice around Antarctica as a large insulating blanket covering the Southern Ocean and then visualize a few holes in that blanket, you have some idea of an important process that affects global climate. Scientists call the holes in the blanket *polynyas*—bodies of open water, both large and small, in the sea ice, where sizeable quantities of heat escape to the atmosphere.

The heat that has escaped through these holes, or polynyas, has entered the world's oceans at more temperate latitudes, and has been transported to the Southern Ocean by oceanic currents located at various depths. It is then brought to the surface through complex upwelling and surface wind mechanisms. In many cases, the heat exchange with the atmosphere is restricted by the ice cover. Sometimes, however, large patches of open water—the polynyas—allow heat to cross the ocean/atmosphere boundary.

Thus, we believe that these polynyas, about which relatively little is known, play a principal role from year to year in providing lesser or greater heat exchanges to the atmosphere—depending on the extent of their occurrence. Measurements of the heat lost to the atmosphere through polynyas has proved elusive because of the difficulty of reaching these areas by an icebreaking ship, and because the drift buoys needed to monitor the heat flux without a ship present have yet to be satisfactorily designed.

Some Background

The Earth is heated at low latitudes, and cooled at high latitudes. The efficiency of the atmosphere and ocean, working together, in carrying excess heat across latitudes, determines the mean meridional* temperature gradient of the atmosphere, and hence the vigor of global wind patterns. Since the wind is in itself part of the meridional heat flux process, the whole climate system becomes a complex network of feedbacks—negative feedbacks inducing stability, positive feedbacks nudging the system to ever increasing changes.

The meridional heat transfer mechanisms, as well as characteristics of the radiational balance, depend on the Earth's ocean/continent configuration, which is continuously changing over long geological time scales of tens of millions of years. Of greater concern to civilization are the variations in the global climate at time scales far too short to be associated with the drifting continents—scales of decades to thousands of years. These are forced entirely within the ocean/atmosphere system, with a little help at the tens-of-thousands-year-scale from the Earth's orbital parameters, which alter the distribution of solar radiation over the globe (see also *Oceanus* Vol. 29, No. 4, p. 43). The Southern Ocean, it would seem, plays a key role in governing these swings in climate, including the very significant oscillations between glacial and inter-glacial climate that have been plaguing the Earth for the last million years.

Antarctica and its surrounding ocean are in a unique position in regard to the global climate system. The ocean encircles Antarctica. This not only establishes the major conduit between the three ocean basins, but also isolates the polar continent of Antarctica from exposure to the warm surface waters of the subtropics. It has been doing this for the last 20 to 25 million years, allowing build-up of a massive glacial ice cap resting on the Antarctic continent. The layer of fresh water glacial ice with an average thickness of 3,000 meters, covering an area of 14 million square kilometers, comprises 91 percent of Earth's continental ice. It reaches out to the coast of Antarctica, and along 44 percent of the coastline, forms glacial ice overhangs or ice shelves, floating on the ocean.

The position of Antarctica influences the atmospheric circulation, as great masses of cold air spread away from the dome of polar air over Antarctica, imposing temperature and salinity alterations on the surrounding surface ocean water as sea ice forms and oceanic heat is drawn into the atmosphere. These winds have the additional effect of inducing regional upwelling of subsurface, somewhat warmer, saltier water, as the surface layer is continuously removed by a divergent Ekman transport pattern.* The combination of regional Ekman upwelling and intense thermohaline circulation, or buoyancy forcing by the atmosphere, sets up the Southern Ocean to play a major role in the global climate system.

The sea and glacial ice of the cold regions complicates water mass modification in two ways: the highly spatially and temporally variable sea-ice cover strongly influences the coupling of the ocean and atmosphere in regard to momentum, heat,

* Referring to movement or gradients along lines of longitude; in a north-south direction.

* A wind-induced movement of water in the surface layers of the ocean.

water, and gas exchange; and the ocean interaction with glacial ice influences the characteristics of water masses, and may be a significant factor in glacial ice budgets and global sea level. This ocean/glacial-ice interaction was presented by Stanley Jacobs in an earlier issue of *Oceanus* (Vol. 29, No. 4, p. 50).

While there are many factors within the atmosphere and ocean that might play a role in climate variations, it is exceedingly difficult to isolate specific features in the complex coupled system. There has been much attention devoted to the tropical end of the heat engine, but less attention has been directed toward the polar end. Certainly part of this imbalance stems from the very nature of the environment—it is difficult to obtain information about the harsh, remote, and ice-cluttered polar oceans. Yet, it is in the polar regions of both hemispheres, where the ocean loses great amounts of heat to the cold atmosphere, that a counterbalance to the tropics is formed. How, where, and to what efficiency the polar oceans accomplish this task influences the global climate patterns.

The Southern Ocean and Climate

The global role of the Southern Ocean in terms of the climate system is well recognized, at least in a qualitative sense. The deep-water circumpolar belt permits the establishment of the Antarctic Circumpolar Current. This major current carries ocean water between the three primary ocean basins within an "endless current" as discussed by Thomas Whitworth of Texas A&M (page 53), at a rate of 130 million cubic meters a second. In this way, the three oceans tend to blend their characteristics via the Antarctic Circumpolar Current "conveyor belt."

Poleward of the circumpolar current lies 30 million square kilometers of ocean exposed to the harsh polar atmosphere. Cold water masses form as the warmer deep water, drawn from the north, is chilled as it upwells to the surface layer. These cold Antarctic water masses sink into the ocean interior and spread to the north. The Southern Ocean's influence depresses the temperature of at least 55 to 60 percent of the Earth's ocean volume to below 2 degrees Celsius.

The influence of the Southern Ocean on the rest of the world ocean ultimately depends on the ability of water properties to mix across the Antarctic Circumpolar Current. In the lower 2 or 3 kilometers, this can be accomplished by deep boundary currents supported by submarine ridges that breach the Antarctic Circumpolar Current belt. In the upper 2 or 3 kilometers, this task seems to fall primarily on large eddies, and on the wind-induced northward surface water movement. The difficulty of carrying large amounts of heat by these means attests to the thermal isolation of Antarctica.

Associated with the water mass exchanges between the Southern Ocean and the rest of the global ocean is significant poleward heat flux across 60 degrees South, estimated as 5.4×10^{14} Watts. This ocean heat withdrawn in the Southern Ocean is derived from the heat introduced into the deep water of the world ocean by downward diffusion, and by deep convection of relatively warm salt water in the North Atlantic Ocean (North Atlantic Deep Water).

Southern Ocean Upwelling

The upwelling region between the Antarctic Circumpolar Current and Antarctica has an interesting effect on the ocean: the cold, relatively fresh surface water layer is continuously replaced by upwelling warmer, more saline, deep water. Surface water is removed as about two thirds of it is transported northward to the circumpolar belt, and the remainder to the margins of Antarctica. The total upwelling may be as large as 45 million cubic meters per second. A typical water particle resides in the surface layer only two years. There is not much of a "memory" of the past. Any anomalies in salinity or temperature are quickly washed away.

The deep water upwelling is 2 to 3 degrees Celsius warmer and somewhat saltier than the winter surface water, which is near the freezing point. It is cooled on exposure to the atmosphere and would sink were it not for some freshening of the water by excess precipitation. This compensation is marginal, in that the introduction of fresh water is barely able to maintain a stable stratification. Slight variability in the salinity balance of the surface water could lead to unstable stratification and accelerate deepening of the surface layer, which carries up more heat and salt. This encourages more instability and a still deeper mixed layer; it is a positive feedback. In the extreme, the mixed layer could deepen catastrophically, forming deep-reaching convective cells. We now believe that this condition does indeed happen.

Thus, the newly formed surface water is vulnerable to rather dramatic change—slight alterations in the fresh water balance would spell the difference between floating and sinking. While the net balance of precipitation and evaporation is slightly on the side of stability, the largest factor is the wind-driven divergence of the sea ice. The sea ice moves in response to the wind field. Some areas may experience divergences with net annual production of ice; others exhibit convergence, with net annual melting. Small changes of sea-ice divergences may tip the balance, and deep-reaching convection ensues.

Sea Ice and Polynyas

With the advent of observations from an Earth-orbiting satellite in the early 1970s, a new twist has been added—the extensive winter sea-ice cover apparently is not very stable, as large, ice-free areas, or what we call polynyas, form in the dead of winter. The polynya features are most interesting, since virtually nothing was known about them before the satellite era. Their potential impact on deep ocean overturning is great, in that they greatly alter the nature of the ocean/atmosphere heat and fresh water exchange, and

Icebergs

The B-9 iceberg, 83 miles in length by 19 miles wide (making it larger than the state of Rhode Island), that broke off from the Ross Ice Shelf in October 1987. Reports of a slowed drift in early 1988 led U. S. Navy analysts to suggest that the large iceberg may have been grounded. (Photo courtesy Earth Observation Satellite Company, Lanham, Maryland)

The formation of icebergs in Antarctic waters is an erratic, fluctuating process. After years of build-up, large and small icebergs suddenly "calve," or break off, from glacial ice shelves that extend out over the Southern Ocean from the continent proper. The last two years have seen "some extreme events," according to Stanley S. Jacobs, a previous contributor to Oceanus, *and an oceanographer at Columbia University's Lamont-Doherty Geological Observatory.*

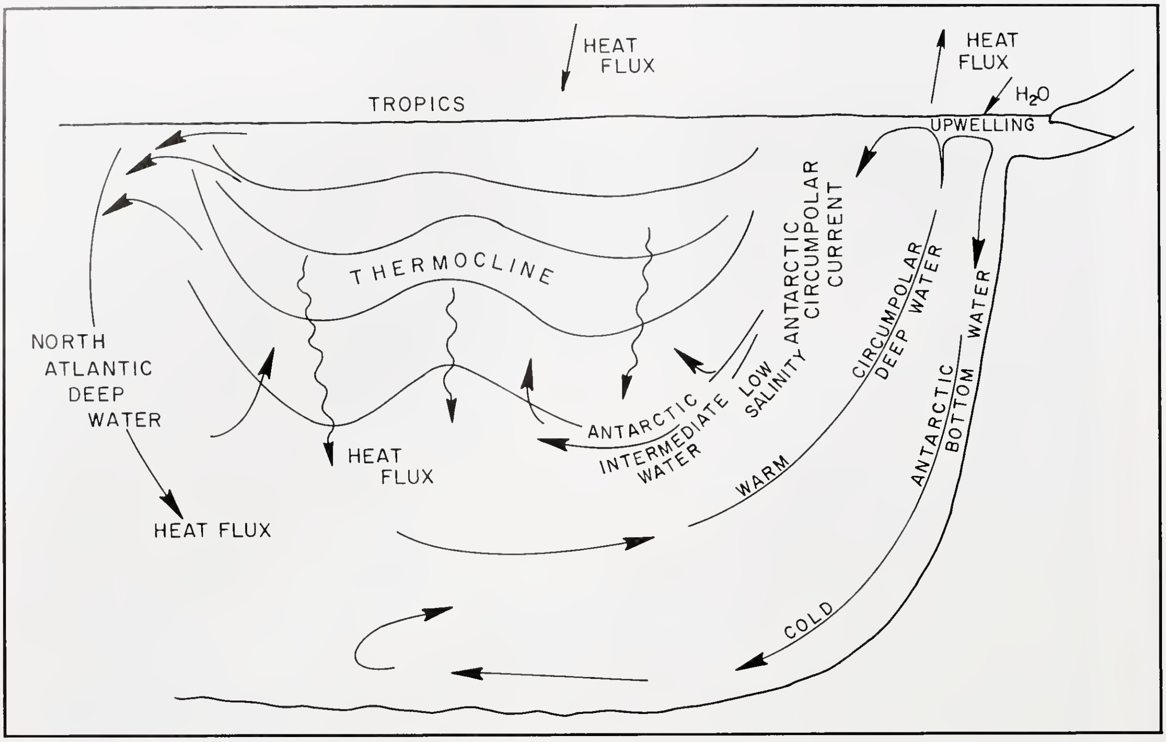
The formation of icebergs is of interest to oceanographers and glaciologists for the role they play in maintaining the mass balance of the ice sheets, and modifying sea-floor sediment patterns. Jacobs has been queried several times about the surprising surge in the number and size of Antarctic icebergs as recorded in 1986 and 1987. The question often is whether the calving events signal a general warming of the Earth. Jacobs replies that there is no cause for alarm. "We are merely seeing a correction in the position of an ice sheet that has been advancing for a few decades, and now has broken off. The extension of ice sheets, and subsequent calving, is a cyclical event, and quite normal. A few decades ago, icebergs like these may have gone unnoticed. But, with frequent satellite observations, and more people in the region, we are more aware of these occurrences."

One large iceberg, called B-9 by the Navy/National Oceanic and Atmospheric Administration Joint Ice Center, broke off from the Ross Ice Shelf last October. It was approximately 83 miles long and took the Bay of Whales site, where Admiral Richard E. Byrd established his first scientific base in 1928, with it. Two or three even larger icebergs split off the Filchner Ice Shelf in 1986, along with another huge one off the Larsen Ice Shelf. These icebergs, monitored by satellite, do not, as is commonly thought, contribute to a global sea level rise—because they actually float on water before the calving events. **—PRR**

hence are of interest to climate studies.

We know from many years of ship reports that the Southern Ocean sea-ice cover undergoes enormous seasonal pulsations, from approximately 4 million square kilometers in early February (summer) to 20 million by September (end of winter). The satellite data obtained by microwave radiometer during the last two decades, provides a view of the complete sea-ice cover on a daily to weekly time frame.

We now know that the ice does not form a continuous blanket. It has many random patterns of



Large-scale meridional circulation of the ocean. The deep water receives heat from the downward diffusion of heat within the main thermocline and by deep convection of relatively warm/salty water in the North Atlantic, associated with formation of North Atlantic Deep Water. The deep water heat is then lost to the atmosphere over the Southern Ocean. This heat loss is associated with formation of the cold Antarctic Bottom Water, which spreads throughout the world ocean. The intensity of the ocean/atmosphere heat exchange is strongly dependent on the nature of the sea-ice cover and existence of persistent open water regions, known as polynyas.

breaks, from the 1- to 10-kilometer scale leads (elongate channels of open water) to the 100-kilometer scale, more persistent, ice-free polynyas.

As sea water freezes, salt is injected into the underlying ocean, encouraging deepening of the mixed layer. The salinity of the sea ice initially is about 30 percent of that of sea water; with aging, more salt is lost to the ocean; toward the end of winter, ice may have a salinity of 15 percent of sea water. Thus, sea ice removes fresh water from the ocean during the formation periods, and releases it on melting.

During the ice-waning period, the melt water is buoyant and floats on top of the ocean; it does not necessarily recombine with the salt released during formation. The winter period salt release boosts the density of the underlying ocean, making it more prone to deep convective events. The sea ice acts to segregate salt from the fresh water—making some ocean areas denser, others less dense.

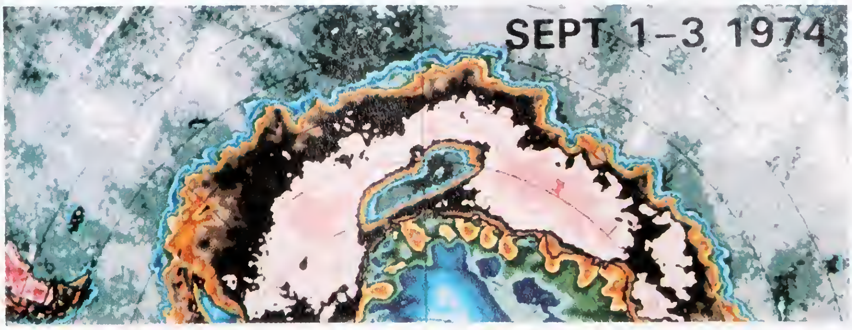
Sea ice influences the energy exchange between ocean and atmosphere, as it damps out the exchange processes of heat, water vapor, and momentum across the sea/air interface. Sea ice insulates the ocean, inhibiting the venting of oceanic heat in winter, and warming of the ocean in summer. This insulation is breached where there are breaks in the ice cover, such as occurs during a polynya event.

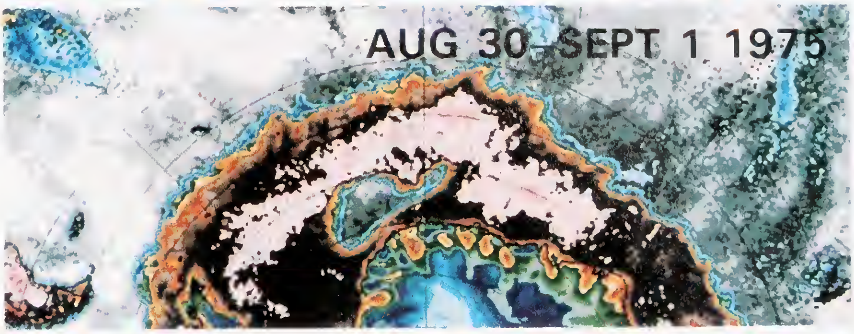
There are two types of polynyas—those forming along the coast of Antarctica, over the continental shelf, and those forming over the deeper ocean to the north. The deep-ocean polynyas occur in regions where the relatively warm subsurface deep water approaches to within 100 meters of the ocean surface, whereas the coastal features are over much colder water columns of the continental shelf.

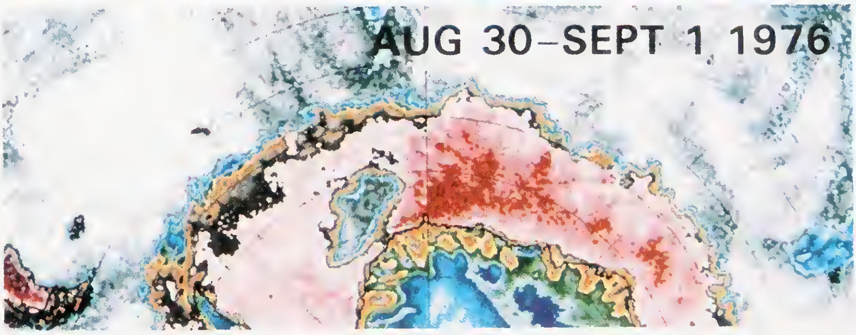
Coastal Latent Heat Polynyas

The water over the continental shelf is exposed to the harshest form of the Antarctic atmosphere, as very cold, dry air flows off the continent. Strong winter winds often remove the insulating cover of sea ice adjacent to the coast. Coastal polynyas are produced as newly formed sea ice is continuously blown offshore. This polynya type can be referred to as *latent heat polynyas,* in that the heat flux into the atmosphere is supported by heat released during ice formation, about 80 calories per gram of ice. These coastal latent heat polynyas become potential sea-ice factories, in which massive amounts of sea ice can form and be quickly transported northward.

Latent heat polynyas do not do much to alter the ocean temperature since the water is close to freezing to begin with, but they do increase the salinity, and therefore density, of the

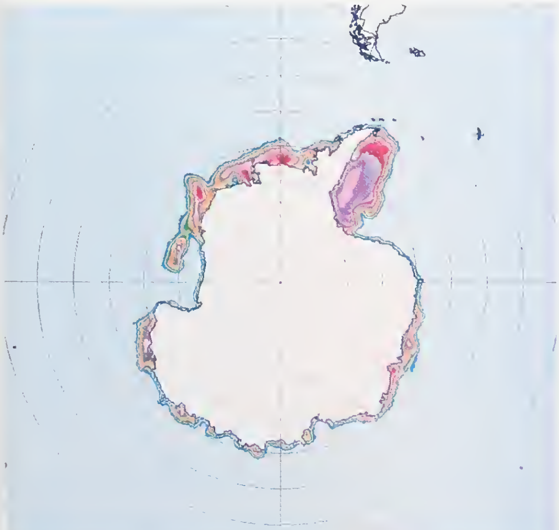




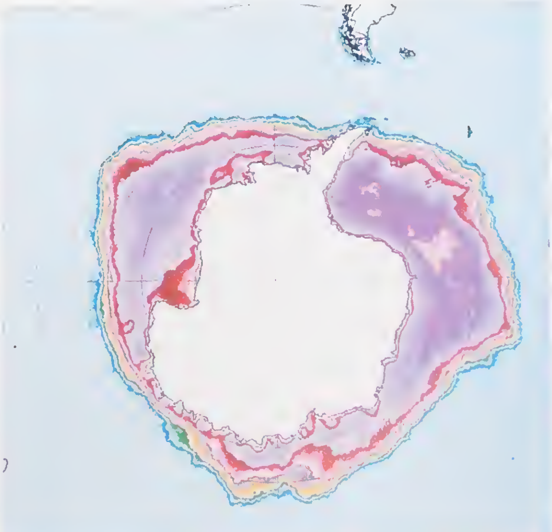


Computer-enhanced images obtained from the microwave radiometer aboard Nimbus satellites. These images are composed of pixels approximately 30 by 30 kilometers, the resolution of the microwave sensors aboard the satellite. The microwave radiation is emitted naturally from the surface ocean and sea-ice cover. The sea ice emits more radiation in the microwave frequency than does the ocean, hence it has a "warmer" or "brighter" radiation temperature. This "brightness temperature" is converted to an approximate sea-ice concentration. (Microwave Radiometer Images supplied by Dr. J. Comiso, NASA)

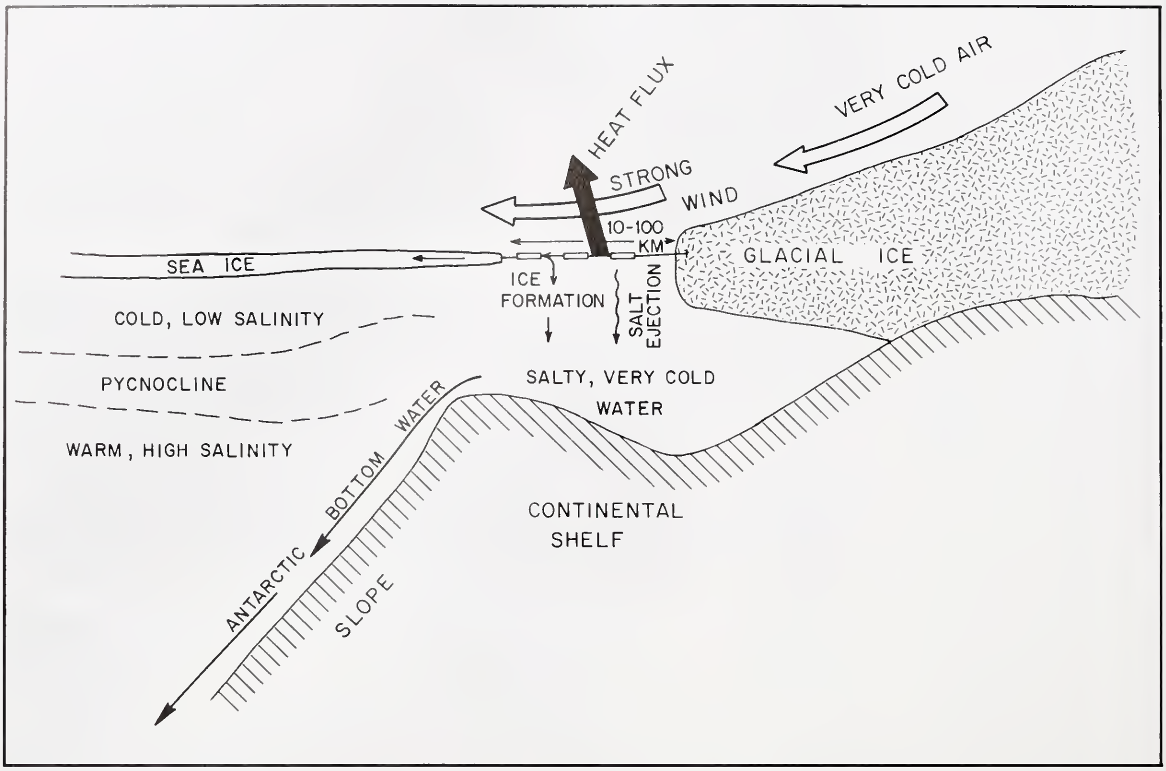
The Weddell Polynya (gray-green area at center—representing open water) on September 1 in 1974, 1975, and 1976 (light blue is the boundary between ice cover and open ocean, pink and purple regions are almost completely ice-covered). The Weddell Polynya slowly drifted westward during its 3-year life-time; this is a consequence of the westward mean circulation of the region, which advects the anomalous weak stratification feature associated with the polynya.



Sea-ice cover for February 1984. This represents the minimum ice cover month.



Sea-ice cover for September 1984. This represents the maximum ice cover month.



Latent heat, coastal polynya. Strong wind blowing off Antarctica removes the sea ice of the coastal region. The open water now exposed to the cold atmosphere, results in formation of new ice. As this ice also is removed by the wind, a persistent coastal polynya forms. These polynyas are maintained by the wind, with the heat flux from ocean to atmosphere supplied by the latent heat of fusion. Massive amounts of sea ice may form within the coastal features.

shelf water as salt is rejected by the forming sea ice. The build-up of salty, dense shelf water drains into the adjacent deep ocean—forming Antarctic Bottom Water.

Latent heat polynyas form along much of the coastline of Antarctica. Antarctic Bottom Water also seems to be produced along much of the coast, though survey of the continental margins is not complete enough to resolve fully all of the production. The coldest, and probably the most, Antarctic Bottom Water is formed in the southwest corner of the Weddell Gyre. A salty variety of bottom water forms in the Ross Sea, and there is evidence of bottom water formation at many other sites around Antarctica. Estimates of circumpolar production rates of Antarctic Bottom Water is in excess of 13 Sverdups (millions of cubic meters per second).

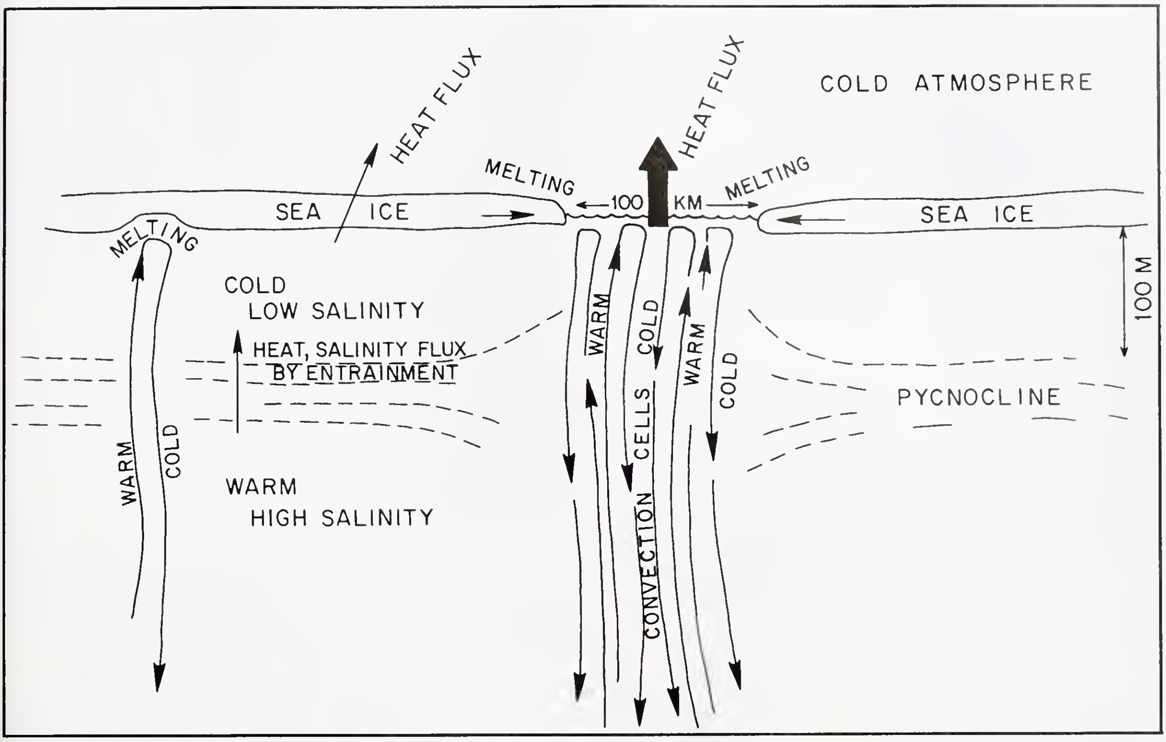
Open-Ocean Sensible Heat Polynyas

Polynyas within the open deep ocean are believed to be maintained by upward flux of massive amounts of the warm deep water balancing downward flux of cold surface water in a convective mode of overturning. The temperature difference supplies the oceanic heat loss to the atmosphere. These polynyas can be thought of as *sensible heat polynyas*—"sensible," in that oceanic heat maintains the ice free conditions. The convective cells are constrained by ocean dynamics to have horizontal scale of only 10s of kilometers. Many cells, standing "shoulder-to-shoulder" are required for the maintenance of sensible polynya features that have characteristic horizontal scales of 100s of kilometers.

A most spectacular open-ocean sensible heat polynya was observed by the microwave satellite during the mid-1970s near the Greenwich Meridian and 65 degrees South—referred to as the Weddell Polynya. During the austral winters of 1974, 1975, and 1976, this large, ice-free region of 300,000 square kilometers drifted westward at 1 kilometer per day, averaged over the 3-year occurrence.

There has not been another occurrence of the Weddell Polynya since 1976, though the microwave data frequently reveal intermittent reduced sea-ice concentration at the Weddell Polynya site, as well as at the Cosmonaut Polynya feature, farther to the east near 66 degrees South and 45 degrees East. These features, which last for 1 to 3 weeks, are believed to result from deep convection, which is not vigorous or extensive enough to maintain a large ice-free region.

Why do some convective cells form large, lasting polynyas, while others do not? The answer may have to do with spatial scale. When convection is triggered under a sea-ice cover, the initial burst of heat melts most, if not all, of the ice immediately above the cell. This creates a stable



Sensible heat, open-ocean polynya. The weak stratification separating the cold surface water from the warmer deep water is destroyed when the surface layer salinity becomes anomalously high. This may be induced by greater sea-ice formation due to surface winds, or perhaps by upwelling of anomalously salty deep water. Once the density of the two layers is the same, further ice formation would force convection. These convective cells are probably 10 to 30 kilometers wide. Individual convective cells may be quite common, but they do not last long enough to melt a "hole" in the sea-ice cover, as the initial melting caps the cell with a buoyant surface layer damping out further convection. When a number of these cells form within a region, a persistent open water feature, a sensible heat polynya, forms. The heat that maintains the polynya is derived from the deep water.

surface film of fresher water, damping out the convection. Each cell would have a characteristic diameter of about 10 to 30 kilometers. In the event of a greater number of cells, standing "shoulder-to-shoulder," the melt region is larger, and more sea ice must be introduced from the surrounding area. The area of convection grows at a rate of the square of its characteristic radius, while the perimeter grows at a linear rate to the same radius.Therefore, as the field of convective cells becomes large, it is possible that the movement of ice into the region cannot occur at a rate fast enough to stop the convection. In this way, a threshold size may occur, above which the convective region can persist, forming a large, enduring polynya. However, what controls the area of convective cells is not known.

The Weddell Polynya clearly left an imprint on ocean characteristics to a depth of 2,700 meters. Comparison of the water column temperature in the area of the Weddell Polynya before and after the polynya event reveals some dramatic changes in the deep water characteristics, noting that the deep waters of the world ocean are considered to be very stable on short time scales. In 1973, the temperature was near +0.5 degrees Celsius just below the cold surface layer. In 1977, the temperature was lower, by as much as 0.8 degrees Celsius, down to a depth of 2,700 meters. The heat removal during this period matched what would be expected for an ice-free polynya situation during the winter period. This heat was thus lost to the atmosphere as convection carried ocean heat to the surface, inhibiting ice formation, and maintaining the polynya condition.

Without more thorough observations of the entire area before, after, and during a polynya event, it is uncertain as to how much water was actually cooled; however, reasonable estimates based on summer field observations suggest that the rate of overturning may have been as large as 6 million cubic meters per second during the winter-active polynya phase, or 3 million cubic meters per second for an annual average. This number would represent a significant percentage, perhaps half, of the total production of Antarctic Bottom Water within the Weddell Sea, a major bottom-water production area to the south.

Sensible heat polynyas result in cooling of the ocean, with perhaps some freshening as ice from the polynya edges migrates into the polynya convective region and melts, though without enough fresh water introduction to shut down the convective overturning. The convection would not

induce a drastic change of the ocean density, though the vigorous vertical displacement of water would remove stratification. The main consequence is enhancement of ocean heat venting—compared to the nonpolynya situation.

Thus we ask questions such as: what initiated, maintained, and terminated the Weddell Polynya? How often does it form? What is its impact on the larger-scale climate system? What effect does it have on the carbon dioxide budget? And, how might the Polynya frequency be altered with the "greenhouse" induced climate change—for example, will there be a positive or negative feedback?

The maintenance seems to be controlled by deep convective overturning. The initiation must have something to do with the salinity balance of the winter surface water. The stability of the surface water "floating" over the deeper warm layer is so slight that deep convective or catastrophic deepening of the mixed layer is possible with only minor increase of surface water density. The delicate marginal stability would be upset if there were a larger upwelling of deep water into the surface mixed layer, a reduction in net precipitation, or a larger divergence of sea ice. Once convection sets in, it would continue—as the upwelling warm deep water is rapidly cooled on exposure to the atmosphere and sinks. The convection would cease only when enough fresh water, presumably from melting sea ice from the surrounding regions, or when summer period warming re-establishes a buoyant surface layer. The reoccurrence of the Weddell Polynya for three consecutive winters, with intervening summers, indicates some "memory." This most likely is related to a surplus of salinity within the surface water from the previous winter, making a repeat performance likely during the following winter.

Why then did the polynya not form in 1977? It is likely that the general circulation carried the oceanic memory of a salty surface layer westward into a region of sea-ice convergence, which essentially flooded the area with fresh water—damping out convection.

Will the Weddell Polynya return? Did it occur before the mid-1970s? In view of the marginal stability of the water column in the Weddell region, it is likely the Weddell Polynya occurred before and will again. Inspection of deep-water temperatures from the available data does indeed suggest that a Weddell Polynya formed in the early 1960s. This was before the satellite era, and so cannot be substantiated with direct observation.

Concluding Thoughts

The remoteness, the environment, and special requirements for observations all have hindered further development of quantitative understanding of the Southern Ocean, particularly within the regions covered by sea ice. Improved prediction of climate trends will be based on improved assessment of the dominant processes and their rates within the Southern Ocean. A well-coordinated attack to answer the many questions is clearly needed. Such an attack is planned during the 1990s as part of the World Ocean Circulation Experiment (WOCE). Discussions are now under way to set out an effective research approach.

The response of the Antarctic ice sheet to the carbon dioxide-induced global warming, a change that is expected to be amplified in the polar regions, is a matter of great concern in regard to sea-level changes. It is important that we fully understand the vertical exchange processes within the Southern Ocean so that they can be incorporated within the global climate models, and their potential negative and positive feedback properties assessed.

Coupled with the ocean/atmosphere heat exchange may be alterations in gas exchange, such as oxygen and carbon dioxide. Gas exchange rates are not even known for the normal sea-ice covered condition, let alone for the polynya condition. However, changes are expected as the winter snow-covered sea ice is removed, with potential impact on the carbon dioxide global budget and "greenhouse" climate change.

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Selected Readings

Comiso, J. C., and A. L. Gordon. 1987. Recurring polynyas over the Cosmonaut Sea and the Maud Rise. *J. Geophys. Res.* 92(C3):2819–2833.

Carsey, F. 1980. Microwave observations of the Weddell Polynya. *Monthly Weather Review* 108:2032–2044.

Gordon, A. L. 1982. Weddell deep water variability. *J. Mar. Res.* 40 (supplement):199–217.

Gordon, A. L., and B. A. Huber. 1984. Thermohaline stratification below the Southern Ocean sea ice. *J. Geophys. Res.* 89(C1):641–648.

Jacobs, S. S. 1986. The polar ice sheets: A wild card in the deck? *Oceanus* 29(4):50–54.

Toggweiler, J. R., and J. L. Sarmiento. 1985. Glacial to interglacial changes in atmospheric carbon dioxide: The critical role of ocean surface water at high latitudes. In: *The Carbon Cycle and Atmospheric CO_2 Natural Variations Archean to Present*, Sundquist and Broecker, eds. Geophysical Monograph 32, pps. 163–184. Washington, D.C.: Am. Geophys. Union.

Zwally, H. J., J. C. Comiso, and A. L. Gordon. 1985. Antarctic offshore leads and polynyas and oceanographic effects. In: *Oceanology of the Antarctic Continental Shelf, Antarctic Research Series*, Vol. 43, ed. S. S. Jacobs, pp. 203–226. Washington, D.C.: Am Geophys. Union.

The Antarctic Ozone Hole

by Mario J. Molina

Last October, the ozone concentration over Antarctica dropped to the lowest level ever observed anywhere in the atmosphere. This level was less than half of what it had been a decade ago, during the austral spring. Recent findings have shown conclusively that this "ozone hole" is largely of man-made origin.

Atmospheric Ozone

Ozone is a type of oxygen molecule, with the formula O_3. It accounts for only about 0.0001 percent of all the oxygen in the Earth's atmosphere. The rest is in the form we breathe, O_2. Ozone, created by the action of sunlight on O_2, is an extremely important trace constituent of the atmosphere, as it protects us from the sun's harmful ultraviolet (UV) radiation. Most of it is found at altitudes of between 12 and 25 kilometers. But even there, at its greatest concentration, it is present at only a few parts per million. On the average, ozone is more plentiful near the poles than at the equatorial regions, and more abundant in winter than in summer.

At ground level, ozone is produced locally by the action of sunlight on automobile exhaust

and other industrial emissions; it is a chemical toxic to plants and animals. While concentrations of ozone in polluted urban air can reach levels dangerous to life, industrially produced ozone does not significantly contribute to the concentrations found in the stratospheric "ozone layer." At higher altitudes, however, rather than posing a threat to life, ozone absorbs most of the sun's UV radiation that reaches Earth, preventing the radiation from reaching the Earth's surface, where it could cause serious damage to many biological systems. While absorbing this radiation, ozone heats the atmosphere, creating a global "inversion layer," where the temperature increases with altitude; this gives rise to the stratosphere—the atmospheric shell between altitudes of 10 and 50 kilometers. The layer below the stratosphere—the first shell, or troposphere—contains only about 10 percent of the Earth's total ozone.

Antarctic Ozone Measurements

In 1985, a team led by Joseph C. Farman of the British Antarctic Survey published an article in *Nature,* reporting a dramatic decrease in ozone levels during springtime over Halley Bay (Figure 1). Their observations were confirmed by other groups using different methods, including the National Aeronautics and Space Administration's (NASA's) Nimbus-7 satellite. This satellite provides continuous worldwide coverage of the atmospheric ozone abundance. The Nimbus-7 data showed that

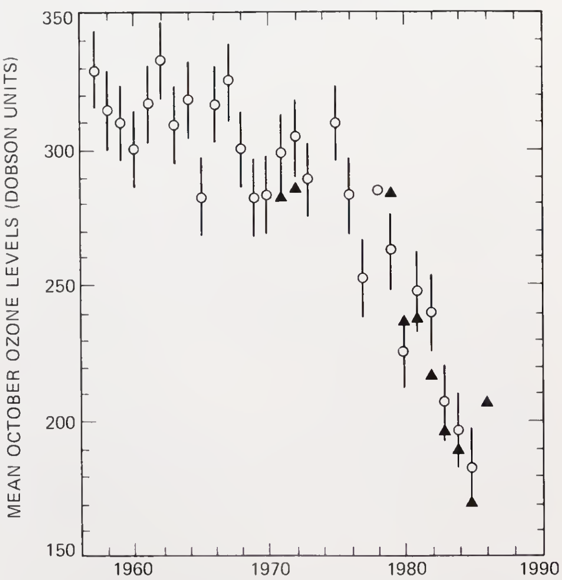

Figure 1. The total amount of ozone measured in October since 1956, directly over Halley Bay by J. Farman and co-workers of the British Antarctic Survey (open circles), and from NASA satellite measurements (solid triangles). The universally accepted measure for total ozone, a "Dobson unit"—equal to one hundredth of a millimeter—corresponds to the thickness of the layer that would result if all the atmospheric ozone above were to be brought to ground level, at standard temperature and pressure.

the region of ozone depletion was somewhat wider than Antarctica, and that it was more or less restricted to the lower stratosphere (altitudes of 12 to 25 kilometers). This unusual "hole" opens in September, with the first light of the Antarctic sunrise, and closes in mid-October. It has been deepening since the late 1970s.

The discovery of this mysterious hole was not expected by atmospheric scientists in particular, and disturbed the scientific community in general. A change in ozone concentration of this magnitude suggested to scientists that the ozone layer is influenced by processes they had not previously recognized. Researchers all over the world raced to develop plausible explanations. Eventually, two sets of theories dominated the field—redistribution theories, and chemical destruction theories. It was possible that the hole was the flip side of a compensating *increase* in ozone concentrations elsewhere, caused by dynamic meteorological processes. On the other hand, proponents of chemical destruction theories believed that unforeseen chemical processes were causing the Antarctic ozone to vanish.

The Role of Chlorofluorocarbons

In a 1974 *Nature* article, the author and F. Sherwood Rowland of the University of California, Irvine, alerted the world about a potential depletion of stratospheric ozone because of chlorofluorocarbons (CFCs) released into the atmosphere. CFC molecules consist of chlorine, fluorine, and carbon atoms. Because of their unusual stability and low toxicity, CFCs were regarded as ideal industrial chemicals, and are used widely in refrigeration, foam insulation, aerosol sprays, and solvents in the microelectronic industry. Ironically, it is this chemical inertness that allows CFCs to survive for so long in the environment, and eventually to diffuse above the ozone layer, where they are broken apart by solar UV radiation. The decomposition products include chlorine atoms, which speed up the destruction of ozone through a catalytic cycle.*

In the 14 years since the CFC ozone depletion theory was first proposed, scientists around the world have studied it in the laboratory, by field measurements, and by computer simulations. All methods have essentially confirmed its validity. The presence of CFCs in the stratosphere was proven by measurements. Their concentrations were found to decrease rapidly with increasing altitude, as expected, because of destruction by solar UV radiation. Both atomic chlorine and chlorine monoxide were detected in the stratosphere, supporting the notion that a chlorine-catalyzed chain reaction is actually occurring there.

According to very conservative calculations widely reported in the research literature, the total amount of ozone in the atmosphere will decrease by several percent by the end of the century,

* A catalytic reaction often involves an increase in the rate of a chemical reaction, induced by a "third-party" agent that is unaltered by the reaction.

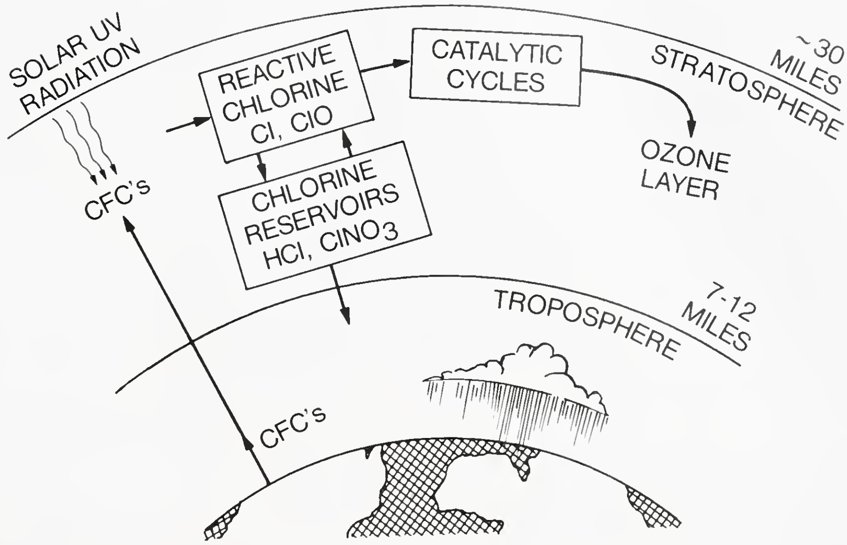

Figure 2. Chlorofluorocarbons (CFCs) are industrial chemicals released at ground level. They are unaffected by rain and by the chemical reactions that cleanse most other gases in the troposphere. The CFC's slowly rise into the upper stratosphere, above the ozone layer, where ultraviolet radiation is strong enough to break the molecules apart, releasing chlorine atoms that react very rapidly with ozone. Occasionally, these chlorine atoms combine with other chemicals to form relatively stable "chlorine reservoirs," which in turn decompose, periodically returning the free chlorine atom to the stratosphere. Each chlorine atom released by the decomposition of a CFC molecule is capable of destroying tens of thousands of ozone molecules before it returns to the Earth's surface.

assuming (probably incorrectly) the emission of CFCs continues at present rates. This decrease would barely be discernible among the large natural ozone fluctuations, but the depletion is predicted to occur mostly in the upper stratosphere, where most of the ozone is produced (this depletion has been recently confirmed by observations). In the lower stratosphere, ozone levels could actually *increase* somewhat, partially compensating the losses higher up.

Even if the total amount of ozone were to remain the same, a substantial redistribution could have a serious impact on climate, by changing the temperature profile of the atmosphere. One of the worrisome aspects of the problem is the long time scale involved; the effect of a release of CFCs at any given time is only felt about a decade later, and then it persists for more than a century. Levels of chlorine in the stratosphere are expected to continue increasing for many decades, even if production and release of CFCs were to level off.

In response to public concern over the effects of CFCs on stratospheric ozone, the United States banned the use of CFCs as propellants in aerosol sprays in 1978; Canada, Sweden, Denmark, and Norway subsequently imposed similar regulations. In September 1987, 24 nations—including the United States and nearly all the major industrial countries—signed an agreement to freeze their annual use of CFCs at 1986 levels, and to cut these levels by a half by 1999. This historic agreement, known as the "Montreal Protocol," must be ratified by at least 11 countries to become official in 1989.

Stratospheric Chemistry over Antarctica

Conditions in the stratosphere over Antarctica are different in many respects from those in the temperate and equatorial latitudes. High-energy solar UV radiation is scarce over the poles; and the temperatures are the lowest of any in the atmosphere. Normally, the catalytic cycles responsible for ozone creation and breakdown (Figures 2, 3, and 4) are active only at higher temperatures, and in the presence of abundant solar UV radiation. This explains why ozone is neither generated over the poles nor normally destroyed there, so a chemical explanation of the ozone hole requires a different mechanism.

One such explanation assumes that high solar activity—correlated to the 11-year sunspot cycle—produces large amounts of ozone-destroying nitric oxide. This so-called "solar-cycle" theory predicts that high concentrations of oxides of nitrogen should be present in the Antarctic stratosphere. The solar-cycle theory is the only plausible "natural" chemical destruction mechanism proposed. All other chemical explanations involve chlorine compounds which are, for the most part, man-made.

Some of the chlorine in the stratosphere comes from the methyl chloride (CH_3Cl) that is a by-product of marine life. However, the contribution from industrially derived CFCs clearly dominates at present; this source has more than doubled its contribution during the last 15 years.

Atmospheric scientists have identified several chlorine-based processes that could explain

the ozone hole. They suggest that polar stratospheric clouds (PSCs) could play a major role in such processes. These high-altitude clouds were discovered many years ago, and are peculiar to Antarctica. Worldwide, the stratosphere is very dry and normally cloud free, although it has a thin haze, or "aerosol layer," that consists predominantly of tiny, wet, sulfuric acid droplets. The abundance of these droplets increases markedly after large volcanic eruptions. Over Antarctica, however, stratospheric temperatures drop to below −85 degrees Celsius during the winter, cold enough for the scarce water vapor to condense and form thin ice clouds. It is conceivable that these clouds could facilitate the conversion of chemically bound, and relatively inert forms of chlorine—the chlorine "reservoirs"—into active chlorine.

The work of the author and others at the California Institute of Technology's Jet Propulsion Laboratory (JPL) showed that the reaction between chlorine nitrate and hydrogen chloride—the two most abundant chlorine reservoirs—occurs very slowly in the gas phase. It occurs so slowly that, in the context of observable ozone depletion, it does not occur at all. But in the presence of various solid substrates, about one out of every 10 collisions between chlorine nitrate and hydrogen chloride molecules results in molecular chlorine and nitric acid (HNO_3). This is an example of a "heterogeneous" chemical reaction, which is a reaction occurring on a solid or liquid surface. Further experiments carried out at JPL showed conclusively that the ice-particle-mediated reaction goes to completion often enough to generate quantities of molecular chlorine sufficient to cause the ozone hole.

This particular reaction on the ice surface could explain how chlorine can rapidly be released from the inactive reservoirs to its most active form, free atomic chlorine, since even the faint radiation available over Antarctica in the spring can break chlorine molecules apart into their constituent chlorine atoms. Another important characteristic of the PSC-mediated reaction is that the other product, nitric acid, remains frozen in the ice. In this way, the nitrogen oxides are kept out of the gas phase and so cannot interfere with the chlorine cycles. These experimental results have been supported by other, independent, studies—for example, by David Golden and his co-workers at SRI International in Palo Alto, California.

This still leaves unexplained how a *catalytic cycle* of ozone destruction might be maintained. Such a cycle is necessary to account for the high rate of Antarctic ozone destruction that has been observed. Chlorine atoms react very rapidly with ozone, even at the low temperatures prevailing over Antarctica, producing oxygen molecules and chlorine monoxide. However, the second step in the ozone destruction cycle (Figure 4) operating at mid-latitudes does not occur over the poles. Oxygen atoms are too scarce to react at any appreciable rate with chlorine monoxide. Three catalytic cycles that regenerate chlorine atoms, and that do not require oxygen atoms, have been proposed as being at work over Antarctica.

First of all, the author's earlier work at JPL led to the idea that chlorine monoxide could react with itself, producing the "dimer" molecule, Cl_2O_2. The dimer could decompose by several pathways, regenerating free chlorine atoms. Secondly, Michael McElroy and co-workers at Harvard University proposed a bromine cycle, involving the reaction of chlorine monoxide with bromine monoxide (BrO). The product of this reaction would be atoms of bromine and chlorine. The third cycle, suggested by Susan Solomon of the National Oceanic and Atmospheric Administration, F. S. Rowland, and others, involves the hydroperoxy

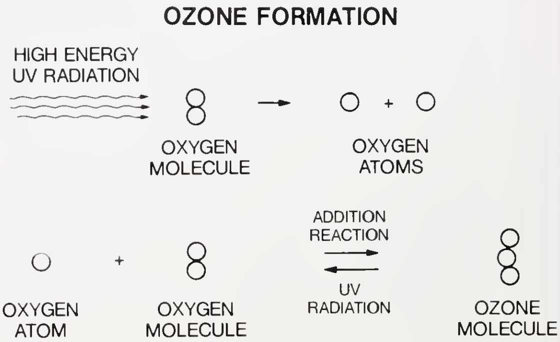

Figure 3. Highly energetic solar UV radiation breaks apart an oxygen molecule into its constituent oxygen atoms, which combine rapidly with other oxygen molecules to form ozone. In the process of shielding the Earth from solar UV radiation, ozone breaks apart, but is quickly regenerated.

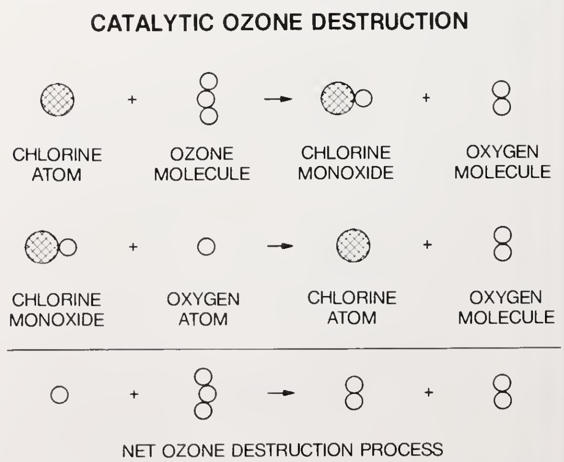

Figure 4. In a catalytic destruction cycle at mid-latitudes, the reactive chlorine atoms and chlorine monoxide are recycled. An ozone molecule and an oxygen atom disappear, forming two oxygen molecules. Natural control of ozone occurs mainly through a catalytic cycle involving nitric oxide (NO) instead of atomic chlorine, and nitrogen dioxide (NO_2) instead of chlorine monoxide, yielding the same "net" ozone destruction reaction.

radical (HO_2), produced by the decomposition of water vapor, reacting with chlorine monoxide, eventually releasing free chlorine atoms.

The net effect of these three cycles is to destroy two ozone molecules and produce three oxygen molecules, while returning all the other reactants to their original chemical form.

Measurements Over Antarctica

Field measurements over Antarctica now comprise a wealth of information, helping to support or refute the various theories for ozone depletion. During the austral spring of 1986, the first National Ozone Expedition (NOZE I) followed the formation of the hole from the National Science Foundation's (NSF's) research station at McMurdo Sound. Scientific reports resulting from the expedition suggested a chemical process involving CFCs as the most likely cause for the ozone hole, although natural causes were not entirely ruled out.

A second expedition (NOZE II) to McMurdo station in 1987 gathered additional data. At the same time, another ambitious expedition was coordinated by NASA, probing the Antarctic stratosphere with an ER-2 aircraft—a modified version of the military U2 spy plane—and a DC-8 as platforms for sophisticated measurements. This expedition, known as the Airborne Antarctic Ozone Experiment, was able to range more widely in terms of both area and altitude.

Preliminary results from the aircraft expedition are consistent with the observations made the previous year from McMurdo. The combination of those results and observations show that the chemical composition of Antarctic stratosphere is highly perturbed, compared to predictions based on "natural" chemical and dynamical theories. One of the key experiments, conducted by James Anderson's team from Harvard University, monitored chlorine monoxide levels. The levels were found to increase sharply, as soon as the airplane penetrated the so-called "chemically perturbed" region, reaching a maximum of 100 times the level normally measured at mid-latitudes. At the same time, ozone levels dropped just as sharply. The concentrations of the two species were highly anticorrelated, that is, behaving like mirror images of each other.

Measurements carried out by other teams also supported the theory of CFCs being responsible for Antarctic ozone destruction. Nitrogen dioxide was present at extremely low levels, whereas nitric acid (measured as nitrate) was present in the ice particles. The hydrogen chloride levels were low during the early stages of the ozone hole formation, returning slowly to normal levels as the hole disappeared with the breakdown of the polar vortex.* There were low concentrations of CFCs and nitrous oxide in the regions of diminished ozone, indicating that the air in those regions was not coming from the troposphere below, but was "aged" stratospheric air. This air would have come from higher altitudes at equatorial or temperate latitudes, according to conventional views about the large-scale circulation in the stratosphere.

These findings rule out the natural, or solar-cycle, theory that requires high levels of nitrogen dioxide. They also are incompatible with the "dynamics only" theory, postulating an upward movement of tropospheric air as the sole cause of the hole. In contrast, the observed abundance of key chemicals in the ozone hole fits well with the prediction of the chlorine-based theory. The low values of nitrogen oxides observed are consistent with laboratory results showing the chlorine reservoirs to react on the surface of polar stratospheric clouds (PSCs), enhancing the abundance of active chlorine, and at the same time tying up the nitrogen oxides in ice crystals as frozen nitric acid.

The ozone-destroying catalytic cycle that is most likely to occur over Antarctica involves the chlorine monoxide dimer (Figure 5). However, resolving the details of this mechanism depends on further laboratory work on dimer chemistry. The observed concentration of bromine monoxide was too low for the bromine cycle to be the dominant mechanism in ozone destruction. It is clear that meteorology sets up the special conditions required for the perturbed chemistry. As the polar vortex cools, it permits the formation of PSCs.

A wealth of information is still coming out of the expeditions and important results will continue to be announced throughout 1988, as the data is scrutinized further. Much remains to be learned, and many questions need to be answered about the detailed interpretation of the results, but the overall picture of the chemical origin of the ozone hole as due to CFCs is emerging convincingly.

Antarctic Implications

The 1987 Antarctic ozone hole was the deepest ever; less than a half of the ozone present on August 15 remained by October 7, with more than 97 percent vanishing at certain altitudes. A very worrisome aspect of last year's hole was that the breakdown of the polar vortex occurred about a month later than usual. This implies that the stratospheric meteorology in the Southern Hemisphere can be seriously perturbed by the presence of the hole. Lower temperatures, caused by less solar UV radiation absorption by the diminished ozone, favor the formation of a more stable polar vortex. Hence, the hole might last longer, growing outward from Antarctica; it cannot get much deeper than it is.

The NSF is funding two research groups to help assess the effect of the ozone hole on ecology. Because the sun is always very low in the horizon over Antarctica, the amount of UV radiation screened by the ozone layer is greater than in temperate zones. Nevertheless, the amount

* The polar vortex is a stream of air maintained in the Antarctic stratosphere. It exists for several months each year, and does not mix with the surrounding air. As a consequence of this isolation, the air of the polar vortex becomes very cold.

of UV light reaching Antarctica's surface is certainly greater beneath the ozone hole than elsewhere, or before the hole opens. The consequences for living creatures are unclear. For example, marine phytoplankton and krill might be adversely affected. These organisms are at the base of the Antarctic food chain.

Global Implications

Another aspect worthy of consideration, beyond the large, local ozone depletion effects, is the net ozone depletion in the atmosphere. Half of the ozone is removed over Antarctica, which covers about 10 percent of the area of the Southern Hemisphere. Hence, ozone will be reduced by about five percent throughout that hemisphere as the polar vortex breaks down, and its air mixes with the lower latitude air.

We now recognize that chemical reactions on solid particles suspended in the stratosphere might be more important than previously thought. This could be particularly important in the future, as chlorine levels increase.

A large ozone hole is not likely to form over the Arctic, because a strong vortex does not develop there. The Arctic ice sheet is flat, in contrast to the Antarctic continent, so it is less likely to induce the characteristic upward spinning motion in the atmosphere. As a consequence, PSCs are not as prevalent over the Arctic, but they certainly also occur there, and so can induce chlorine chemistry similar to that occurring over Antarctica.

There are indications that the chlorine monoxide levels in the Arctic stratosphere are higher than expected. Recently, a panel of experts assembled by NASA established that there is a decrease of more than 5 percent in ozone levels during the boreal winter at latitudes above 50 degrees North, with less depletion toward the equator. This drop is much larger than expected from "conventional" chemistry alone.

If the furor over the Antarctic ozone hole has shown us one thing, it is that mankind has the potential to seriously perturb the atmosphere. It is important for society to learn more about worldwide pollution events—such as the ozone hole—to better prevent the uncontrolled deterioration of its environment.

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Acknowledgment

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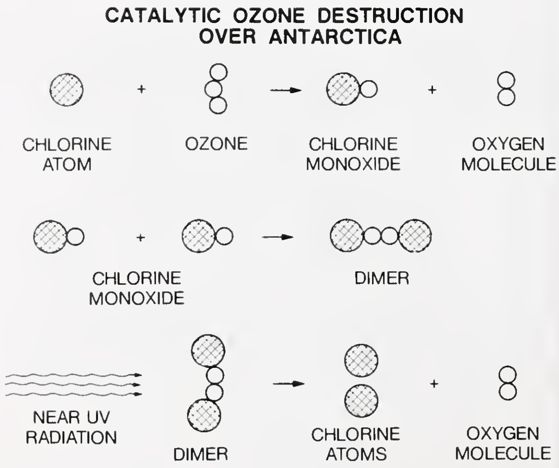


Figure 5. Catalytic cycles over Antarctica do not involve oxygen atoms, which are too scarce. One of the proposed mechanisms involves the dimer of chlorine monoxide. The net reaction is equivalent to two ozone molecules reacting with each other to produce three oxygen molecules.

Selected References

Farman, J. C., B. G. Gardiner, and J. D. Shanklin. 1985. Large losses of total ozone in Antarctica reveal seasonal ClO_x/NO_x interaction. *Nature* 315: 207–210.

McElroy, M. B., R. J. Salawitch, S. G. Wofsy, and J. A. Logan. 1986. Reductions of Antarctic ozone due to synergistic interactions of chlorine and bromine. *Nature* 321: 759–762.

Molina, M. J., and F. S. Rowland. 1974. Stratospheric sink for chlorofluoromethanes: Chlorine atom catalyzed destruction of ozone. *Nature* 249: 810–812.

Molina, M. J., T.-L. Tso, L. T. Molina, and F. C.-Y. Wang. 1987. Antarctic stratospheric chemistry of chlorine nitrate, hydrogen chloride and ice: Release of active chlorine. *Science* 238: 1253–1257.

Solomon, S., R. R. Garcia, F. S. Rowland, and D. J. Wuebbles. 1986. On the depletion of Antarctic ozone. *Nature* 321: 755–758.

World Meteorological Organization. 1986. Global ozone research and monitoring project, Report No. 16. *Atmospheric ozone 1985: Assessment of our understanding of the processes controlling its present distribution and change.* Geneva, Switzerland: World Meteorological Organization.

The Antarctic Circumpolar Current

by Thomas Whitworth III

The Earth's only global current flows east around Antarctica without beginning or end, its 24,000 kilometer length unobstructed by continents. In the middle of the South Pacific, it passes just south of

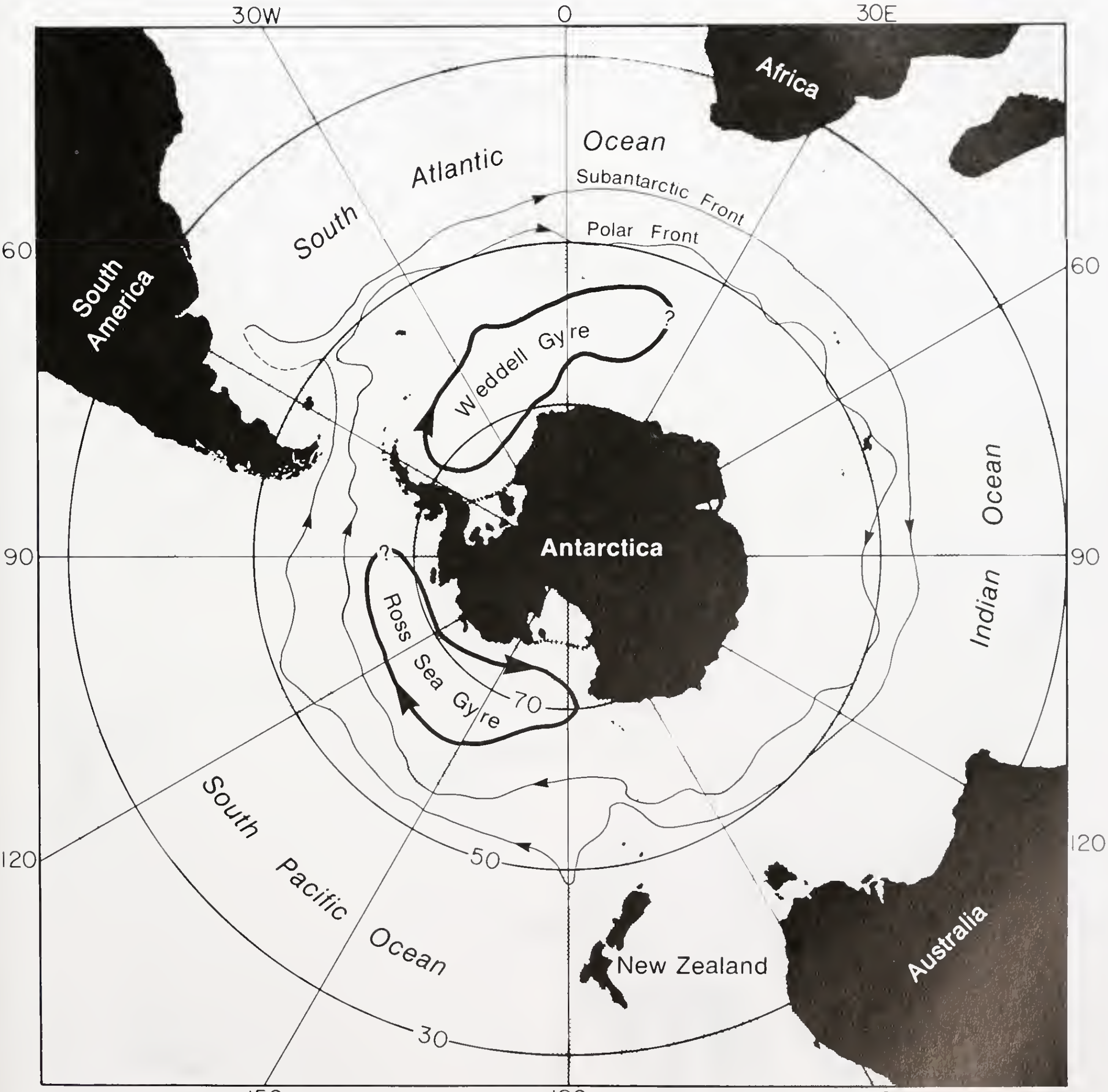


Figure 1. The path of the Antarctic Circumpolar Current is shown by the two single lines, which trace the two major current jets. Heavy lines show the locations of two of the subpolar gyres of the Southern Ocean. Water depths shallower than 3,000 meters are shaded. (Contours are based on data from the Southern Ocean Atlas *by A. L. Gordon and E. J. Molinelli, and from other sources)*

the world's most distant point from land. Even in austral summer (December, January, and February), air and water temperatures along its route remain close to the freezing point, and 40-knot winds and 10-meter seas are not uncommon. It is of little consolation to the scientists who endure these conditions to study the Antarctic Circumpolar Current that in some sectors of the Southern Hemisphere, the current is closer to the equator than Paris is.

The Antarctic Circumpolar Current (ACC) is usually considered the northernmost section of the Southern Ocean, a sea not separate physically from the three oceans to the north, but separate in its biological and hydrographic environment. The frigid air and ice of the Southern Ocean, and the salt left behind during sea-ice formation, combine to produce the densest water on Earth. The cold, nutrient-rich surface water supports an abundance of marine life, and the current sharply delineates the cold waters and distinctive biota of the Antarctic from the warmer waters of the subtropical South Atlantic, South Pacific, and Indian oceans.

Although the ACC does delineate two oceanic environments, it is not an impermeable barrier between the Antarctic and subantarctic. More importantly, perhaps, along lines of latitude, it actually acts as a conduit that connects the world's oceans. Most of the waters carried in the circumpolar current do not acquire their temperature and chemical characteristics locally in the Southern Ocean, but from a mixture of waters formed in other parts of the world. For example, in the North Atlantic, Arctic waters combine with those of the Mediterranean Sea, flow south across the equator, and join the circumpolar current. Over the centuries, this constant trickle of North Atlantic water, and contributions from other sources, have formed the predominant water mass in the current. From the ACC, this water spreads both to the north (becoming the bottom water of the equatorial Pacific, for instance) and to the south (where it is a primary ingredient of dense Antarctic Bottom Water). The circumpolar conduit also has the potential for widespread distribution of less desirable products, such as pollutants.

Current Structure

Unlike other currents, the circumpolar current is not a single broad flow, but consists of two or more relatively narrow jets. Figure 1 shows the approximate locations of the two most prominent current cores. Throughout much of the Southern Ocean, the two jets run parallel to the mid-ocean ridge system that rings the Antarctic continent. South of the circumpolar current are the clockwise flows of at least two subpolar gyres, the Weddell and Ross Sea gyres. We are not sure of the extent of the subpolar gyres, or even their number—a third gyre may exist in the Indian Ocean sector.

Surface speeds within the jets are about 1½ knots, considerably less than in the Gulf Stream, where average speeds are greater, and may reach 5 knots. But, unlike the Gulf Stream, the eastward flow of the jets in the ACC extends all the way to the ocean bottom. Current records from a depth of 3,000 meters south of South America reveal 1-year average speeds of more than a ¼ knot, with occasional bursts to almost 1 knot. The enormous volume of water that is transported in the circumpolar current is accounted for by the great vertical extent of the ACC jets.

The current does not flow strictly along lines of latitude, but tracks both to the north and south. The most poleward excursions of the ACC are south of New Zealand, where the current is forced between the continental shelf and the mid-ocean ridge, and in the Drake Passage, between South America and Antarctica. East of these two places, the ACC turns to the north, and, off the east coast of South America, a branch of the circumpolar current reaches far enough north to collide with the warm, southward-flowing Brazil Current.

Within this general path, the jets are not always found at the same latitude, and may meander hundreds of kilometers north or south of the locations in Figure 1. As in the Gulf Stream, the current cores occasionally wrap back on themselves to produce isolated current rings that can carry a miniature Antarctic marine environment north of the ACC, or a subantarctic environment to the south. Rings and eddies represent one way that the circumpolar current exchanges water properties with the adjacent oceans.

Zones and Fronts

Despite its great length, the circumpolar current appears to be quite uniform, and has similar characteristics no matter where it is observed. A good place to look at the current is at the Drake Passage, between South America and the islands that lie just north of the Antarctic Peninsula. Figures 2a and 2b show oceanic characteristics across the passage.

Ocean fronts are narrow regions (50 to 100 kilometers wide) where there is an abrupt horizontal change in the properties of the water. In Figure 2, the fronts of the ACC appear as sharp depth changes in the contours of equal temperature and salinity (isotherms and isohalines). Since these two properties of seawater are the ones that determine density, lines of constant density (isopycnals) would parallel those of temperature and salinity. An abrupt change in the depth of an isopycnal implies a strong current, and in the Southern Hemisphere, denser water to the south signals a current toward the east (into the page on Figure 2). The current cores in Figure 1 are thus easily identifiable in cross-sections of temperature or salinity.

There is nothing subtle about fronts in the Southern Ocean. Antarctic waters are so dense that lighter waters from the north undergo huge depth changes in overriding them. The 1-degree-Celsius isotherm is deeper than 3,500 meters on the northern side of Drake Passage, and shallower than 1,000 meters on the southern side, just 600 kilometers away. (Although this slope is dramatic by oceanographic standards, it amounts to an angle

of only about a quarter of a degree. If Figure 2 were wide enough to use the same scale in the horizontal as is used in the vertical, the 1-degree isotherm would be almost horizontal.)

The late Sir George Deacon, former director of Britain's National Institute of Oceanography, and a pioneer of modern Antarctic oceanography (see profile, *Oceanus* Vol. 28, No. 1, p. 90), was the first to notice, in 1939, that isotherms rose to the south across the current in a series of steps, implying the presence of more than one front. The Polar Front (earlier called the Antarctic Convergence) was recognized as early as 1901, because its location is often marked by a rapid change in surface temperature. From his work on the British research ship *Discovery,* Deacon showed that the Polar Front (the southernmost contour on Figure 1) was circumpolar in extent.

In subsequent years, the northern contour in Figure 1, representing the Subantarctic Front, also has been shown to be circumpolar. Although vertical sections through the ACC in other parts of the Southern Ocean show a feature similar to the Continental Water Boundary, the southernmost front in Drake Passage, it is not yet known whether this front is part of the current.

The fronts separate distinctive "zones," each characterized by a particular vertical stratification in temperature and salinity. South of the Polar Front in the Antarctic Zone is a layer of water colder than 0 degrees Celsius just below the surface. During winter, this cold water is formed at the sea surface and is about 100 meters thick. (The data in Figure 2 were collected in austral summer, however, and seasonal heating of the surface had isolated the "winter water" below the surface.)

As one moves away from the Antarctic continent, and into the Polar Frontal Zone—a transition between the Antarctic and subantarctic zones—this cold, fresh water sinks to a depth of about 500 meters, and, north of the ACC, continuing to move equatorward, it sinks to a depth of 1,000 meters. This characteristic water mass, known as Antarctic Intermediate Water, spreads throughout the Southern Hemisphere, and its Antarctic characteristics can still be recognized as far north as the equator, and beyond.

The most voluminous water mass in the ACC is called Circumpolar Deep Water, and is not of Antarctic origin. In Figure 2b, water with salinity greater than about 34.7 parts per thousand (of salt to water) is Circumpolar Deep Water, and it constitutes more than half the water in Drake Passage. Its high salinity can be traced directly back to the outflow from the Mediterranean Sea.

In the movement, rising, sinking, and layering of water masses in the region, temperature and salinity play complex and interchanging roles. While the winter water formed in place during the Antarctic winter is cold, it is relatively fresh. The warmer, but saltier water that has some of its origin in the Mediterranean, takes on a greater density, and is located beneath the winter water.

In the Antarctic Zone, therefore, Circumpolar Deep Water lies beneath the winter water, so that between 200 and 500 meters, water

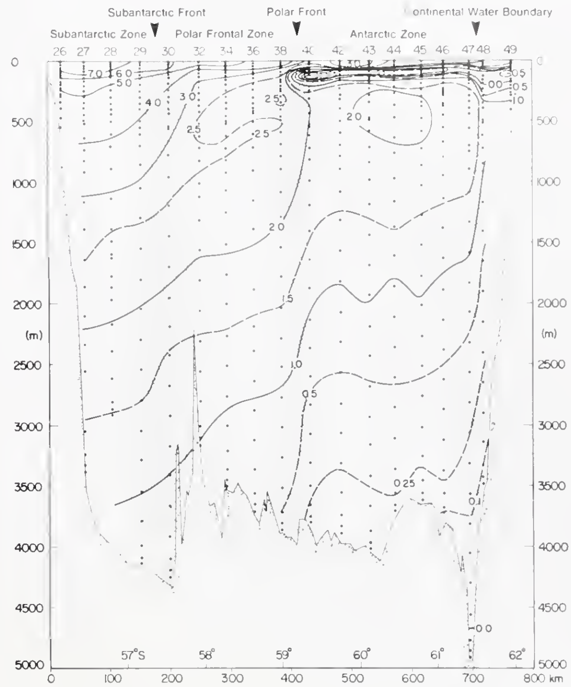


Figure 2a. Vertical section of temperature through the Antarctic Circumpolar Current at Drake Passage, off the southern tip of South America. The three fronts (shaded) that comprise the current are relatively narrow compared to the zones they separate. The dots represent the positions of hydrographic stations and locations of samples collected. The view is looking eastward, from the Pacific toward the Atlantic, or downstream along the current.

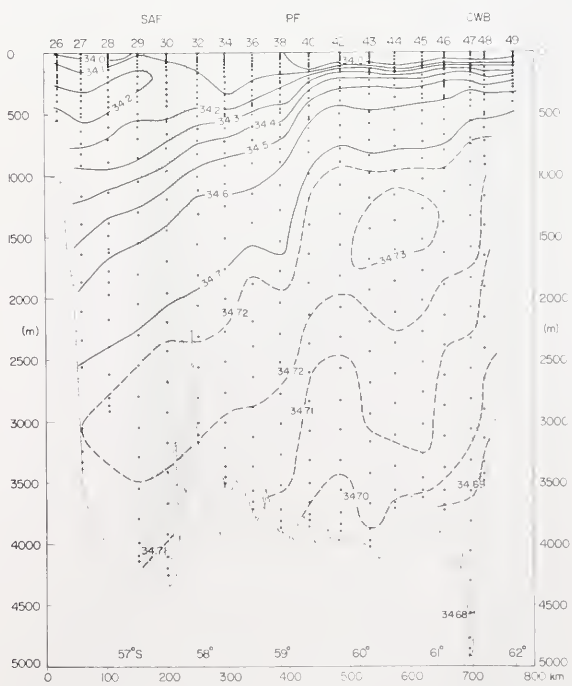
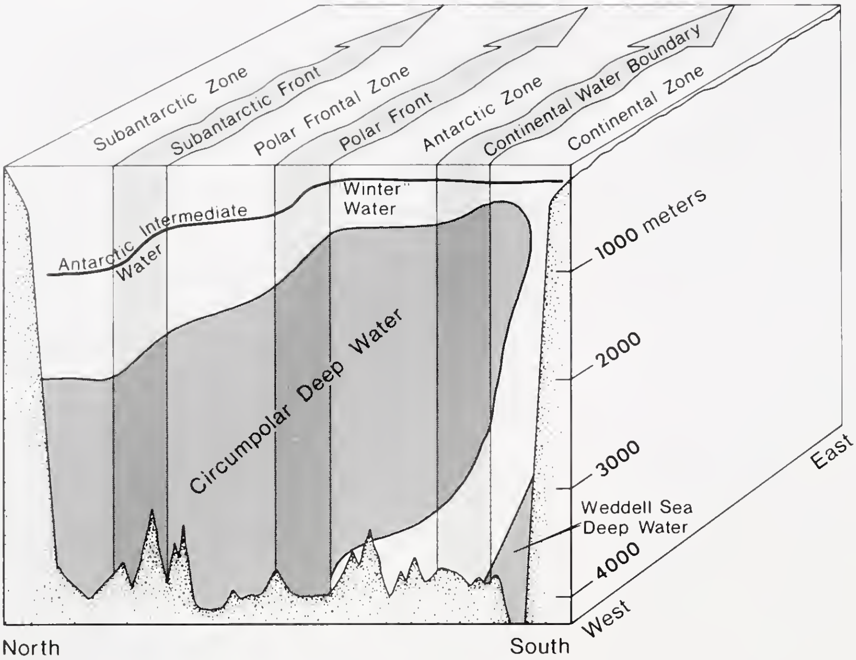


Figure 2b. Vertical section of salinity in parts per thousand (salt to water) through the Drake Passage.



The zonation of the Antarctic Circumpolar Current at the Drake Passage, and the principal water masses.

temperature increases with depth. This unusual situation was first documented in the 1770s during Captain James Cook's circumnavigation of the Southern Ocean.

The ACC nearly fills the Drake Passage as it squeezes through it. The only water in Drake Passage that is not part of the ACC is at the southern margin. Cold and relatively fresh water from the Weddell Sea leaks around the Antarctic Peninsula and flows to the west through the Drake Passage, in the direction opposite to that of the ACC.

Transport

The average transport of the circumpolar current is 130 million cubic meters per second—about four times that of the Florida Current portion of the Gulf Stream system, and about 400 times greater than the transport of the Mississippi River. Even though it represents only 2 months production of a leading cola manufacturer, a million cubic meters of water is a large volume, and may be difficult to visualize. A railroad tank car holds about 100,000 liters (30,000 gallons), and it would take almost 9,000 of them in a train 200 kilometers long to carry a million cubic meters. To carry the amount of water passing through Drake Passage each second would require four trains, each stretching from Miami to Seattle.

The volume transport of the ACC is an important number to oceanographers. If all the pertinent dynamics are included in numerical models of global ocean circulation, a realistic transport estimate for the ACC must result. As we will discuss later, the present models do not pass the transport test.

The first calculation of the transport of the ACC was made in the early 1930s. It differed from today's best estimate by only 15 percent. All of the early estimates were made without sophisticated instruments or electronics, using an indirect calculation based on the slope of isopycnals across the current. When reliable current meters were developed and first deployed in the ACC, transport estimates actually got worse—because of undersampling or oversampling of the fronts, which transport most of the water. For example, at Drake Passage about three-fourths of the transport occurs in the three frontal regions shaded in Figure 2, even though they occupy only about one-fourth of the cross-sectional area of Drake Passage.

A comprehensive study of the ACC at Drake Passage was started in 1975 as part of the International Southern Ocean Studies program. The program involved scientists and technicians from Texas A&M University, Oregon State University, Woods Hole Oceanographic Institution, Lamont-Doherty Geological Observatory of Columbia University, the University of Washington, Scripps Institution of Oceanography, and colleagues from Chile and Argentina. During the 6-year study, 11 cruises on 7 different research ships were made, and some of the huge amount of data collected is still being analyzed. An important personal observation made by the author was that, during the program the weather at Drake Passage underwent constant improvement—at least, the fifth cruise did not seem nearly as bad as the first.

One of the major goals of the International Southern Ocean Studies program was to make a dependable estimate of the transport of the ACC and its variability. As the final experiment of the program, an array of 91 instruments on 24

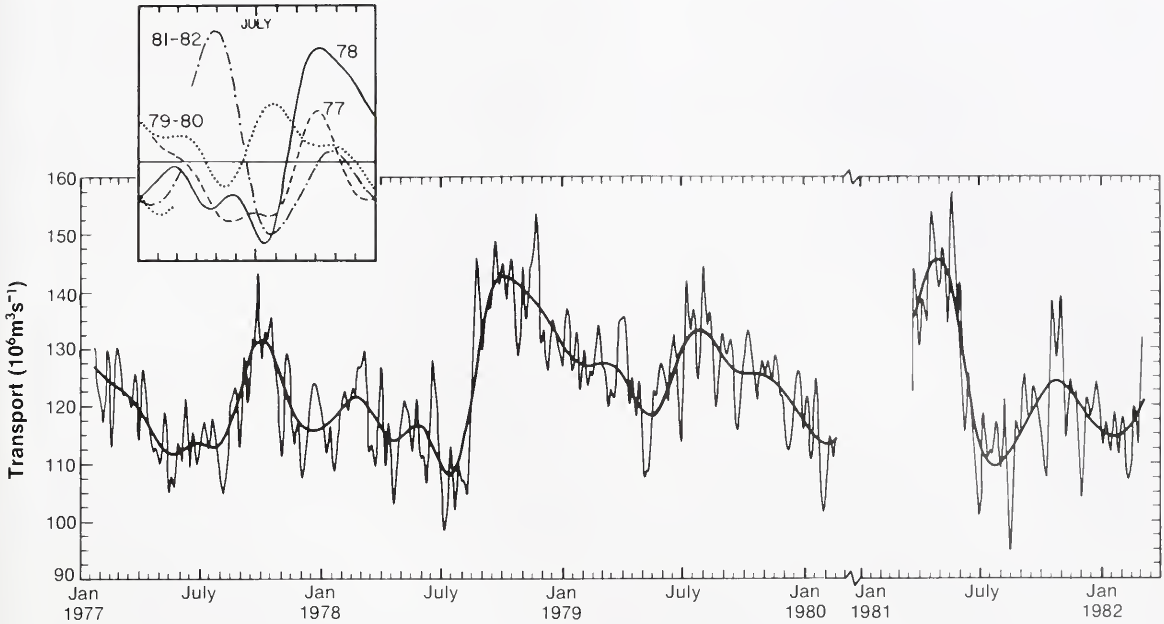


Figure 3. Time series of water transport through the Drake Passage. The light line shows fluctuations in transport that occur at periods longer than 10 days. The heavy line is a smoothed version of the data to illustrate the longer-term changes in transport. The inset shows the smoothed data as four 1-year segments, and demonstrates that year-to-year differences in transport are larger than any seasonal similarities. The units of transport are in millions of cubic meters per second.

moorings was deployed in Drake Passage for 1 year. Moorings were placed about 50 kilometers apart so that the fronts could be sampled adequately, even as they meandered back and forth through the passage. Even though the average transport for the year was quite close to the 50-year-old estimate, it was now a reliable estimate, and we had our first look at how the transport changed with time.

The 1-year transport estimate was later extended in time—using the relationship between volume transport and the pressure difference across Drake Passage as measured by bottom-mounted precision pressure gauges. Figure 3 shows the transport between 1977 and 1979, and during 1981. Most surprising are the rapid increases and decreases in transport (amounting to nearly 40 percent of the average) in time spans of just a few weeks. The inset shows 1-year segments of the volume transport, and although there is some suggestion of a seasonal pattern in the transport variability, differences from year-to-year are very large. Much of the small-scale variability can be explained by 2-week solar and lunar tides. The larger, longer-period fluctuations remain unexplained. But, describing the variability is a first step toward understanding what causes it.

Forcing and Braking

The "Roaring Forties" of the Southern Hemisphere are the result of atmospheric high-pressure cells near 30 degrees South, and low-pressure cells near the coast of Antarctica. The strong winds from the west pushing on the sea surface are what drive the circumpolar current. Curiously, the winds are stronger than they need to be to produce a current the size of the ACC. Numerical models of wind-driven ocean circulation that work well in other oceans fail when applied to the Southern Ocean.

One reason for the failure of the models (the models produce a current that is about 10 times too strong) is that the ACC never flows near a coastline where its momentum can be reduced through frictional dissipation. To create a realistic ACC, modelers must increase the internal frictional parameters of the models so that the water is unrealistically "sticky." The real problem in understanding the ACC is not what drives the current, but what keeps it from being even stronger than it is.

There are two leading candidates for applying the brakes to the ACC. The first is the force applied to the current by the extensive system of bottom ridges in the Southern Ocean. The second theory relies on the observation that the ACC does not flow due east everywhere, but in two places (east of both New Zealand and South America), the current actually turns to the north. In these places, the ACC can be thought of as a short western boundary current—a mini-Gulf Stream. Such boundary currents can dissipate large amounts of energy in small-scale eddies, turbulence, and other unpleasantries collectively known to modellers as nonlinearities.

Shuffleboard Aboard the Melville

Current meter mooring deployments in rough seas and on wet decks are dangerous operations. Each part of the procedure is carefully orchestrated to minimize the danger of moving heavy pieces of equipment close to the edge of the deck. But at least once, the excellent safety record of the Oregon State University Buoy Group was maintained only through divine intervention.

Preparations were underway to deploy a mooring, and the R/V Melville *was maintaining slight headway into a heavy swell to minimize the ship's motion. A stack of railroad-wheel anchors was about to be moved astern and secured near the site from where it would be dropped into the water—after the rest of the mooring had been deployed and was floating behind the ship. Somehow, the ship turned into the "trough," parallel to the seas, and began rolling wildly. The stack of wheels broke loose from the one remaining bolt holding it to the deck, and began to lumber toward the low side of the ship. On the next roll, it seemed inclined to return to its original position, but instead rammed into another stack, shearing off the restraining bolts of a second anchor. Very soon, the stern of the* Melville *was a huge shuffleboard court, but with disks more appropriate for a curling match among giants. With cries to the bridge to resume their heading, the deck crew scrambled for ladders, cranes, poles, or anything above deck level.*

Once the Melville *was back on course, the anchors, some weighing more than a ton and a half, littered the deck in precarious motionlessness, some half overboard, held tenuously by a filament of dacron line. Ever so cautiously, they were coaxed back to their homes and re-secured. Apart from jangled nerves, there were no injuries, but the* Melville *probably still has some mysterious indentations in her rails.*

— TW III

Neither theory can be easily tested through field work, and the answer to this question will have to await more sophisticated models on larger computers. The fundamental question of how the ACC works remains a major research challenge for the future.

A Vital Link

The world's longest current plays a vital role in global ocean circulation by serving as a pathway for interocean exchange of water. Despite years of study, we remain ignorant of many important aspects of the Antarctic Circumpolar Current—why it looks the way it does, goes where it goes, and why it is not even stronger than it is.

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Selected References

Deacon, G. 1984. *The Antarctic Circumpolar Ocean.* 180 pp. Cambridge, England: Cambridge University Press.

Gordon, A. L., and E. J. Molinelli. 1982. Thermohaline and chemical distributions and the atlas data set. In, *Southern Ocean Atlas.* 11 pp., 233 plates. New York: Columbia University Press.

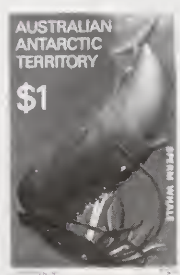
Nowlin, W. D. Jr., and J. M. Klinck. 1986. The physics of the Antarctic Circumpolar Current. *Reviews of Geophysics and Space Physics,* 24(3): 469–491.

Sievers, H. A., and W. D. Nowlin, Jr. 1984. The stratification and water masses at Drake Passage. *Journal of Geophysical Research* 89(11): 489–514.

Whitworth, T., III, and R. G. Peterson. 1985. Volume transport of the Antarctic Circumpolar Current from bottom pressure measurements. *Journal of Physical Oceanography* 15(6): 810–816.

Antarctic Marine Living Resources

by Kenneth Sherman, and Alan F. Ryan



One most often thinks of whales as the biological resource of the Antarctic. Since the cessation of commercial whaling, however, finfish and krill are the targets of the fishery. Like whales, these resources have been subjected to poorly regulated or unregulated fishing pressures—sometimes to the point of stock reduction and depletion.

Fishing for krill (the dominant species) and finfish began in Antarctic waters in the 1960s, and has continued to the present. Fish catches in the waters of the Southern Ocean increased from approximately 4,000 metric tons in the 1972–73 season to a peak of 500,000 metric tons in the 1979–80 season. The targets included species like the Antarctic cod, *Notothenia rossii*, and the ice fish, *Champsocephalus gunnari*, both of which are now depleted. Krill have been fished in the Antarctic since 1973, when 20,000 metric tons were landed. Since then, the catch has been highly variable, increasing to 446,000 metric tons in 1986.

For the most part, the major interest in these Antarctic marine living resources (krill and finfish) developed after the 1959 Antarctic Treaty. Since mechanisms for governing resource activities were not addressed adequately in the treaty itself, the parties to the Antarctic Treaty decided to pursue a new international agreement specifically tailored to address the resource issues.

An Ecosystems Approach

Since the turn of the century, and on through the mid-1970s, studies concerned with the natural production of living marine resources have been focused on the population dynamics of single species, often without consideration of the influence of environmental change on populations. Traditionally, studies on the birth, growth, feeding, reproduction, and death of fish have looked for links to water characteristics (such as temperature and salinity), circulation, water depth, and the like.

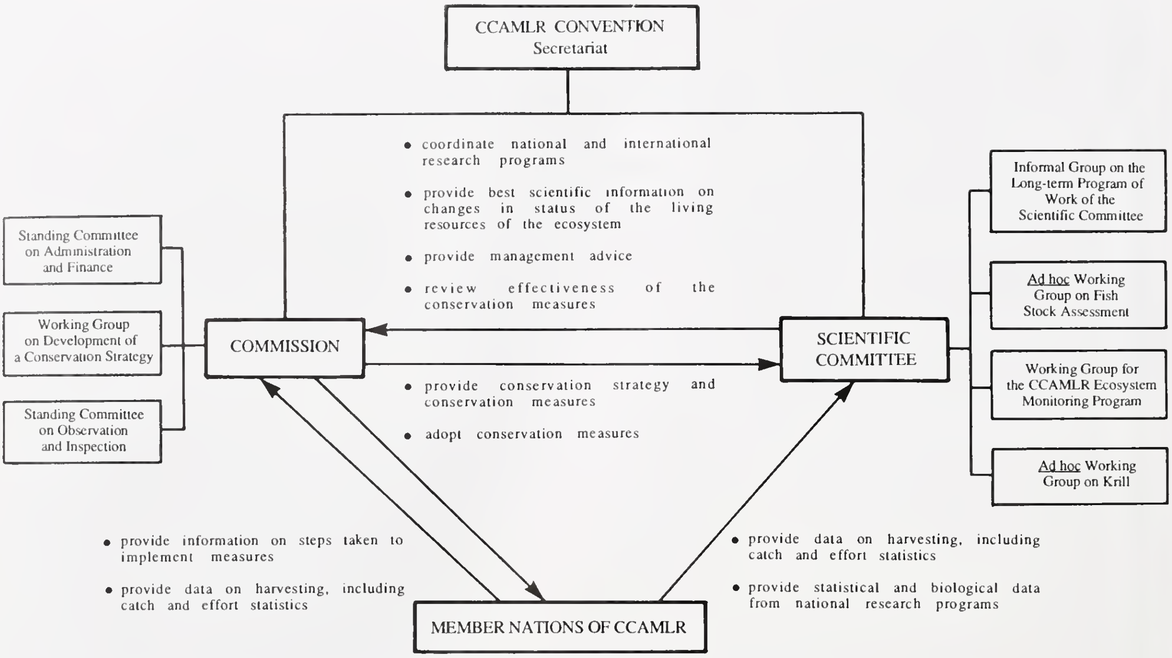


Figure 1. Organizational structure of the Convention on the Conservation of Antarctic Marine Living Resources (CCAMLR).

Predator/prey relationships have likewise been considered.

However, with new sampling techniques and the capabilities of more powerful computers, understanding the dynamics of any one fish species will more fully take into account the complex interactions of environmental characteristics with other species sharing that environment—providing an ecosystem perspective that includes multispecies interactions.

CCAMLR

The Convention on the Conservation of Antarctic Marine Living Resources (CCAMLR) is an international agreement that supports an ecosystem approach to the conservation and management of living resources found in ocean areas surrounding Antarctica. The convention mandates a management regime committed to applying measures to ensure that harvesting of Antarctic species, such as finfish and krill, is conducted in a manner that considers ecological relationships among dependent and related species. The implementation of CCAMLR is carried out against a background of enlightened international activities in Antarctica, that in recent decades have been concerned with scientific research and cooperation, demilitarization, denuclearization, resource utilization, and environmental protection. The parties to the convention have conducted their activities under the system of legal, political, and scientific relationships established by the Antarctic Treaty of 1959.

The CCAMLR was negotiated from 1977 to 1980, entering into force in 1982. The CCAMLR Convention Area includes the marine area south of the Antarctic Convergence, the boundary between 48 and 60 degrees South separating the cold Antarctic waters and the warmer subantarctic waters. South of this boundary is defined as the Antarctic marine ecosystem. The convention applies to "the populations of finfish, mollusks, crustaceans, and all other species of living organisms, including birds, found south of the Antarctic Convergence."

Member countries of the CCAMLR have established an organizational structure (Figure 1) to assist them in the conservation and management of the Antarctic marine ecosystem. The major operational units of the CCAMLR system are the Commission for the Conservation of Antarctic Marine Living Resources (the "Commission"), and the Scientific Committee for the Conservation of Antarctic Marine Living Resources (the "Scientific Committee"). A secretariat resides at CCAMLR headquarters in Hobart, Tasmania, Australia. Its function is to serve the commission and the scientific committee of the CCAMLR, including organizing the annual meetings and acting as a clearing-house for communication with member countries.

The CCAMLR Commission

Members of the Commission for the Conservation of Antarctic Marine Living Resources are: Argentina, Australia, Belgium, Brazil, Britain, Chile, the European Community, East Germany, France, India, Japan, New Zealand, Norway, Poland, South

Africa, South Korea, the Soviet Union, Spain, the United States, and West Germany.

The functions of the commission are to:

- *facilitate study of Antarctic marine living resources and the ecosystem of which they are a part;*
- *compile data on the status of, and changes in the distribution, abundance, and productivity of harvested and dependent or related species and populations of Antarctic marine living resources;*
- *ensure the acquisition of catch and effort statistics; and*
- *formulate, adopt, and revise conservation measures on the basis of the best scientific information available.*

The commission has met six times. The first and second meetings were largely organizational. The third meeting, in September 1984, produced the first conservation measures for depleted stocks of finfish, and a program of data gathering and consideration of conservation options was initiated. The fourth meeting, convened in September 1985, followed initial mesh-regulation measures for aiding the recovery of fish stocks with the adoption of more stringent regulations prohibiting all directed fisheries for the bottom-living species of Antarctic cod, *Notothenia rossii*, in the waters of South Georgia, the South Orkneys, and the Antarctic Peninsula. The fifth meeting in 1986 adopted conservation measures prohibiting fishing for the severely depleted Antarctic cod, and permitting the commission to fix catch limitations as a management technique.

The sixth meeting in 1987 established new conservation measures to address the serious depletion of fish stocks. Three measures of significance were taken for the first time—an overall total allowable catch, a reporting system, and a closed season. In addition, a new working group was established to implement, coordinate, and evaluate research on the distribution and abundance of krill.

The Scientific Committee

The Scientific Committee for the Conservation of Antarctic Marine Living Resources, which has the same national membership as the commission, has also held six meetings. It has initiated a substantial program to implement its obligations under Article XV of the convention. They are to:

- *establish criteria and methods for determining needed conservation measures;*
- *regularly assess the direct and indirect effects of harvesting on the status and trends of Antarctic marine living resources; and*
- *formulate proposals for the conduct of national and international research programs related to Antarctic marine living resources.*

Because the status of Antarctic stocks and knowledge of species interactions are limited, the scientific committee is coordinating a program of commercial fisheries data collection and analysis, as well as directed ecological research, to obtain the necessary information. Ongoing basic research also will make contributions to the scientific committee effort.

The CCAMLR Working Groups on Krill Catch-Per-Unit-Effort, Fish Stock Assessment, and Ecosystem Monitoring have begun to address the data and analysis needs, and the directed research activities required to meet the objectives of ecosystem conservation.

Conservation Objectives

Most living resources of the world ocean are subjected to intensive fisheries. Total annual catches of global fisheries reached a level of 98.5 million metric tons in 1986. According to at least one member nation of CCAMLR, the annual yield expected from a less traditional species—Antarctic krill, *Euphausia superba*—could contribute an additional 25 to 30 million metric tons a year to the global fisheries catch. The consequences of a 30-million-metric-ton annual krill fishery to the balance of populations in the Antarctic ecosystem and the objectives of CCAMLR are not clear. However, it appears that lead time is sufficient in relation to present krill catches so that a systematic and enlightened approach to the management of this resource can be implemented.

As nations move from single species management to multispecies fisheries management, it will become necessary to provide greater consideration of the resources and the impacts of natural and human perturbations on the resources within marine ecosystems. The management regime presently in place in CCAMLR reflects this trend, and has adopted a conservation approach that seeks to:

- *prevent any harvested population from falling below the level that ensures the greatest net annual increment to stable recruitment;*
- *maintain the ecological relationships between harvested, dependent, and related populations of Antarctic marine living resources;*
- *restore depleted populations; and*
- *prevent or minimize the risk of changes in the marine ecosystem that are not potentially reversible over two or three decades.*

Although krill catches have not as yet reached critical levels, fish catches have depleted stocks to levels where the objective to ". . . prevent any harvested population from falling below the level which ensures the greatest net annual increment" has been violated.

Fish Stock Depletion

Reports to CCAMLR in 1986 and 1987 warned that the fish stocks of the ocean waters around South Georgia were reduced in abundance. (The Soviet

Union is the primary fishing nation in the region. East Germany and Poland also conduct fishing operations.) The results of a survey conducted during the 1986–87 season by the United States and Poland on the *R/V Professor Siedlecki* indicate that fish stocks are at levels far below their capacity for rapid recovery.

Fish catches in the waters of the Southern Ocean peaked at 500,000 metric tons in the 1979–80 season. During the initial phases of the fishery, the targets included species of the cod-like *Notothenia*. Toward the end of the 1970s, catches of the ice fish, *Champsocephalus gunnari*, increased. The recent survey found that both these stocks are in a depleted condition.

Initial conservation steps were taken by CCAMLR to eliminate the target fishery for Nototheniids. Mesh size of the trawl nets was limited to 80 millimeters to allow the spawning-size fishes to escape through the trawls. Also, area closures were made to protect spawning fish. Because of cold water temperatures, Antarctic fishes are slow in reaching maturity, growing at about half the rate of Atlantic haddock and cod. Therefore, fishing pressure must be eased if depleted populations of Antarctic fish are to recover. Fishery scientists from the United States have been modeling management options for accelerating recovery of the depleted fish stocks, and will present their findings at the 1988 meeting of CCAMLR.

Krill Variability

Joint U.S.-Polish biomass assessments of krill also were made during the 1986–87 research season. Operations were conducted in the vicinity of Elephant Island and within the Bransfield Strait, where large superswarms of krill were detected in 1981. One of the swarms covered several square kilometers to a maximum depth of 200 meters; none of these superswarms were observed from the *Professor Siedlecki* in 1986.

The annual catches of krill have been variable since 1973. In 1980, the catch was 400,000 metric tons; dropping to 128,000 metric tons in 1984, and increasing to 446,000 metric tons in 1986. As with Antarctic fish, the Soviet Union is the principal krill-fishing country, reporting a catch of 379,000 metric tons during the 1985–86 season. Japan is second in krill landings, with annual landings at the 50,000-metric ton level during the same period. Other countries that have participated in krill fishing, but at a very low level (less than 5,000 metric tons annually), include Chile, East Germany, Poland, and South Korea. Japanese trawlers fishing for krill within the U.S.-Polish survey area in January 1987, indicated that commercial concentrations were present in the water column. This was confirmed from acoustic records on *Professor Siedlecki*. NOAA scientists estimated the abundance of krill in the area surveyed at about a half million metric tons.

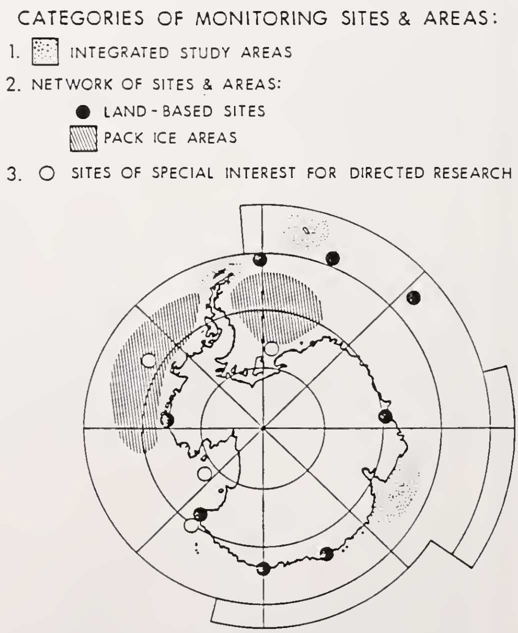
The U.S. scientists concluded that annual, highly variable, krill abundance in the Scotia Sea area is dependent on the presence of oceanographic features (eddies and fronts) that build up concentrations of the planktonic krill. The actual annual abundance levels of krill in the ocean areas of Antarctica remain uncertain.

Although the Scientific Committee of CCAMLR has indicated that the present catch levels of approximately a half million metric tons annually pose no direct problem to recovery of depleted populations of whales, the scientific committee is encouraging member nations of CCAMLR to improve assessments of annual krill production. This would ensure that commercial catches remain at levels that will minimize any adverse effects on dependent populations of whales, seals, fish, and other natural predators of krill.

Ecosystem Monitoring

Monitoring the Antarctic marine ecosystem is an important function of the Scientific Committee of CCAMLR. The objectives of the CCAMLR ecosystem monitoring program are to detect and record significant changes in critical components of the ecosystem; and to distinguish between changes to Antarctic marine populations caused by harvesting of species, and changes due to environmental variability—both physical and biological.

Because the Antarctic marine ecosystem encompasses such an enormous geographical area, it would be unrealistic to attempt studying all areas at once. Hence, the CCAMLR Working Group on Ecosystem Monitoring has identified priority study areas where it has encouraged nations to undertake



Sites and areas designated by CCAMLR for Antarctic ecosystem monitoring programs. Locations are identified according to three research and monitoring categories.

research. The ecosystem research and monitoring program includes time-series monitoring of krill and early life stages of fish along with the measurement of vital parameters of selected predatory species, including fur seals; crabeater seals; minke whales; Adélie, chinstrap, macaroni, and royal penguins; Antarctic and Cape petrels; and black-browed albatrosses. This group of species is the focus of baseline characterization and monitoring studies. Research efforts are designed to detect and quantify changes in behavior, reproduction, growth, condition, and population characteristics of these krill predators in relation to changes in their biological and physical environment.

Planning to Meet CCAMLR Objectives

It was recently agreed that the scientific committee's ability to successfully achieve its goals would be enhanced by periodically updating a long-term program of work. A long-term agenda will be updated in 5-year segments—to ensure the orderly development of the data bases and analyses required to meet obligations specified in the convention. The scientific information will be used to evaluate the effectiveness of management and conservation measures.

Among the measures to be evaluated are those to enhance the recovery of fish stocks; and a system for continuously monitoring the sources, fates, and effects of potentially hazardous marine debris. Progress made in enhancing the recovery of depleted whale stocks also will be evaluated in close collaboration with the International Whaling Commission, the agency responsible for the conservation and management of global whale populations.

A New Approach

The CCAMLR represents a significant milestone in the evolution of a more holistic approach to the conservation and management of living marine resources. The importance of the CCAMLR ecosystems approach is underscored by its membership. Among the countries that are signatories and acceding states are the principal fishing nations of the world, including Chile, China, Japan, the Soviet Union, and the United States. The U.S. fisheries catch in 1985 was equal to Chile's, and represented 6 percent of the world landings. Japan was the leading fishing nation with 13 percent of the catch, followed by the Soviet Union (12 percent), and China (8 percent). Whether these countries will adopt a more holistic ecosystem approach to management of fisheries and other living marine resources following the CCAMLR model remains an open question. The U.S. Under Secretary of Commerce for the Oceans and Atmosphere, William E. Evans, recently stated that he ". . . will persist in urging the ecosystems approach to fisheries management" (*Ocean Science News*, March 1988). Qisheng Tang, Deputy Director of the Yellow Sea Fisheries Research Institute in China, also has recently endorsed the ecosystems approach to fisheries management (*AAAS Selected Symposium on Large Marine Ecosystems*, Westview Press 1988).

A fur seal with a nototheniid fish. This predator/prey relationship highlights one of the complex interactions in the Southern Ocean ecosystem. (Photo by T. S. McCann, courtesy British Antarctic Survey).

CCAMLR is ushering in a new approach to ecosystems management at a crucial time—a time that is highlighted by a growing awareness of global fragility and concerns with the status of living marine resources.

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Selected References

Alexander, L. M., and L. C. Hanson. 1984. Antarctic politics and marine resources: critical choices for the 1980s. In *Proceedings from the Eighth Annual Conference*, held June 17–20, 1984, Kingston, Rhode Island: Center for Ocean Management Studies, The University of Rhode Island.

Laws, R. M. 1984. *Antarctic Ecology*, Vol. II. London: Academic Press.

May, R. M., ed. 1984. *Exploitation of Marine Communities*. Berlin: Springer-Verlag.

Sherman, K., and L. M. Alexander, eds. 1986. *Variability and Management of Large Marine Ecosystems*. AAAS Selected Symposium 99, 319 pp. Boulder, Colorado: Westview Press.

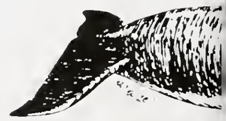
Sutinen, J. G., and L. C. Hanson. 1986. Rethinking Fisheries Management. In *Proceedings from the Tenth Annual Conference*, held June 1–4, 1986, Kingston, Rhode Island: Center for Ocean Management Studies, The University of Rhode Island.

Living Resources:

Whales

by Douglas G. Chapman

Blue whale, Balaenoptera musculus, *to 31 m. (98 ft.)*



Sei whale, Balaenoptera borealis, *about 16 m. (50 ft.)*

Heavy exploitation has greatly reduced Antarctic whale stocks. An important concern is whether these stocks have been reduced below recovery levels. This concern is somewhat difficult to address because of problems associated with estimating whale populations, both at present and pre-exploitation levels.

The world's largest whale stocks are found in the Southern Hemisphere. In the austral summer (December through February), these whales migrate to the Antarctic to feed. In the remote Antarctic waters, whales were mostly exempt from exploitation until the advent of several technological innovations in the late 19th and early 20th Century. These innovations—the development of the explosive harpoon, and the factory ship with its associated fleet of catchers—led to a major attack on Antarctic whales.

The general pattern followed by whalers in the Antarctic was to hunt the larger, more valuable species to depletion, then switch to progressively smaller species. The first focus of exploitation was the blue whale, followed by a switch to the fin whale, then the sei whale, and finally the minke whale (see Figure 1).

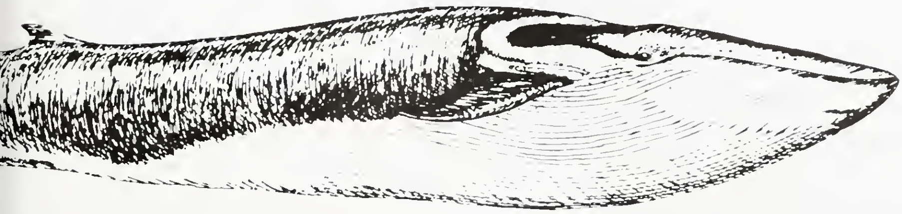
This last switch came just about the time that attention in the western world was being directed to environmental concerns. The obvious depletion of the great whales became a point of focus at the United Nations Environmental Conference held in Stockholm in 1972. Here there was a nearly unanimous vote to seek a moratorium on commercial whaling. Now that such a moratorium is in effect, it is useful to examine the status of these Southern Hemisphere whale stocks—stocks that were heavily exploited for just over half a century. It is also timely to identify the remaining concerns.

Principal Issues

First, as mentioned previously, there is a fear that some stocks may have been harvested to below recovery levels. Second, while there is a moratorium on commercial whaling, this does not necessarily mean that whaling has stopped. Under the provisions of the International Convention for the Regulation of Whaling, member governments of the International Whaling Commission (IWC) may take whales for scientific purposes, and some countries have elected to do so. In particular, Japan is taking minke whales in the Antarctic (see box, page 68). A third point of issue is over the number of whales remaining in any of the stocks, and what numbers might be safely taken, if commercial whaling were to resume. A key to addressing any of these concerns is accurate estimation of whale stocks.

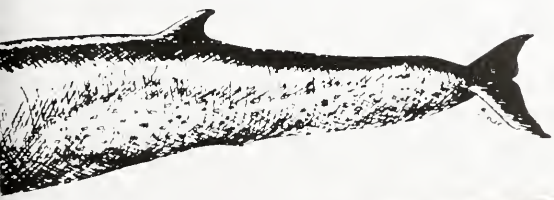
Species of Antarctic Whales

The stocks of whales to be estimated in the Antarctic consist of five major species: blue, fin, humpback, sei, and minke whales. These baleen



Fin whale, Balaenoptera physalus, *about 22 m. (70 ft.)*

Drawings by Bonnie Dalzell and Betty Osborne under the direction of Edward Mitchell. (Courtesy of the Canadian Nature Foundation)



Minke whale, Balaenoptera acutorostrata, about 8 m. (25 ft.)

whales migrate to Antarctic waters to feed during the southern summer.

For the most part, the whales feed on small organisms such as krill (shrimp-like crustaceans) by filtering them through their baleen plates. During the balance of the year, these whales return to more temperate or even subtropical waters to breed and give birth to their young.

Baleen whales feed in several different ranges of Antarctic waters. Blue and minke whales feed furthest south, often concentrating close to, or even among, the pack ice. The second largest whale, the fin whale, generally feeds farther north—the largest catches having been taken between 50 and 60 degrees South latitude, though substantial catches have been taken both north and south of this ring. Humpback whales also feed in this broad range; as they move north to wintering areas, they are most likely to be very close to land. A still more northerly feeder is the sei whale, which was thought to be found mostly in the area of 40 to 50 degrees South latitude. After heavy exploitation of this species began, catches were more widely scattered.

Two other great whales found south of 40 degrees South latitude are the southern right whale and the sperm whale. Right whales were decimated worldwide before the era of Antarctic whaling; though they are occasionally sighted in the Antarctic, such sightings are rare (see also box on page 70). What is known about right whales in modern times comes largely from coastal sightings in temperate waters. The sperm whale—not a baleen whale, but a toothed whale—is even less "Antarctic" than the baleen whales. Only the large males move south of 40 degrees South latitude; the

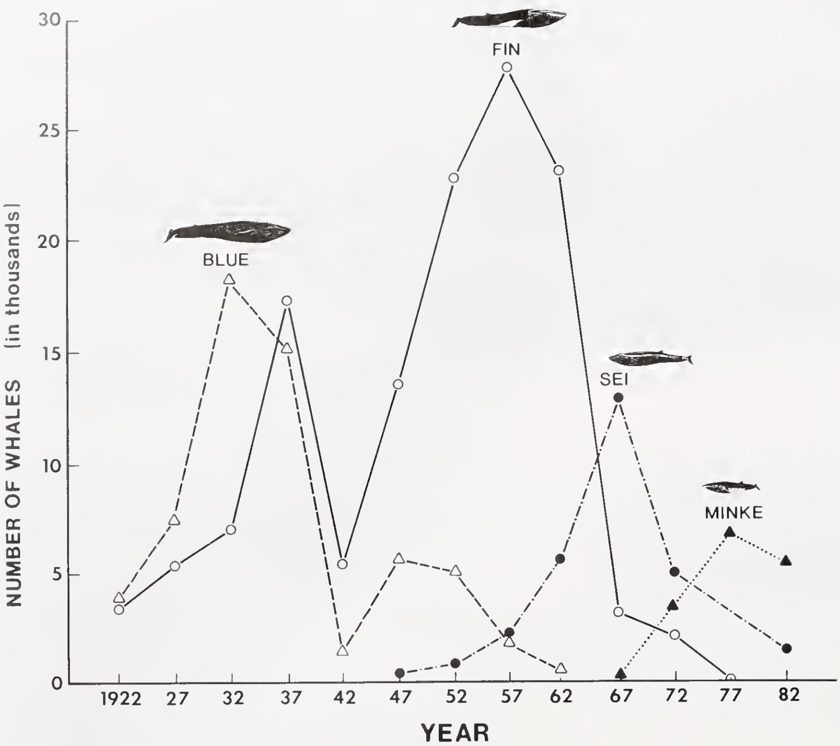


Figure 1. Antarctic baleen whale kill by species, shown as 5-year averages.

females and younger males remain year-around in temperate or subtropical waters. To determine the status of Antarctic whales and subsequently predict their future, their present population size is estimated using several techniques.

Methods of Estimating Whale Stocks

It is difficult to study most wild animal stocks and to determine their numbers. This is particularly true of marine mammals, which are often in remote oceans, and spend much of their time submerged.

Four methods have been used to estimate whale stocks and describe aspects of their population structure and biology: catch-per-unit-effort, mark–recapture analysis, earplug aging, and whale sighting. There are unique problems and uncertainties associated with each method that make it very difficult to compare numbers obtained by the different methods. A further complication is that certain methods work better for certain species, thus levels of accuracy are not even consistent within methods, let alone between them. It is important to look briefly at each of these methods and to be aware of their limitations.

Catch-per-unit-effort. The principle behind catch-per-unit-effort is that as whale populations decrease, the time spent finding a whale should increase. Using this concept, estimates of past whale stocks were extrapolated in the 1960s from existing whaling statistics. The main problems with this method are a lack of consistent data through the years, and the fact that catch per searching hour is not directly proportional to whale density.

Mark-recapture analysis. In mark-recapture analysis, whales are marked with tags, such as the metal cylinders, or "Discovery Marks," initiated by scientists on cruises of the British research vessel, *Discovery*. Assuming that the marked animals mix with the unmarked population, the total population size is estimated from the fraction of marked animals in subsequent samples. The main problems that cause uncertainty in whale marking experiments are the difficulty of shooting a tag from the bow of a ship in the commonly rough ocean waters, and hence the uncertainty whether the placement has been unsuccessful or worse, lethal. In addition, some marks fall out before the animal is captured, while others go unnoticed.

Age data. Two important population characteristics, mortality rate and recruitment rate (the number of whales reaching exploitable size per year), can be estimated from age composition of the population, provided that the population size is stable—which is not always the case. These population characteristics are useful in whale management. Age composition is derived by counting layers in the waxy earplugs that are found in baleen whales. It has been shown, at least for fin whales, that these layers are laid down annually. Earplugs are easiest to read in large animals, making this method accurate only for the larger species. If earplugs are unreadable, or are read with errors, there will be

Table 1. Population estimates of Antarctic baleen whale stocks, with total Antarctic catches, from 1920 to the end of commercial whaling.

Common Name	Species Name	Population Estimates	Date to which Estimate Applies	Method of Estimation	Total Catch[a] since 1920
Blue	*Balaenoptera musculus*	8,000 (Total)	1965–78[b]	Sighting (Japanese scout boats)	307,638[c]
Fin	*Balaenoptera physalus*	70,000 (Total)	1965–78	Sighting (Japanese scout boats)	664,248
Sei	*Balaenoptera borealis*	15,000 (Exploitable)	1979	Analysis using several methods	177,811
Right[d]	*Eubalaena glacialis*	3,000 (Total)	1965–78	Sighting (Japanese scout boats)	Not known
Minke	*Balaenoptera acutorostrata*	436,000 (Total)	1978–84	Sighting (IDCR research cruises)	106,188
Humpback	*Megaptera novangliae*	40,000 (Total)	1965–78	Sighting (Japanese scout boats)	36,504

[a] Some catches have been taken from these stocks at land stations north of 40 degrees South and by pelagic factories operating outside IWC. These have numbered in the low thousands in total, and represent only a small fraction of the total catches listed. The listed catches do include those taken at South Georgia, a land station. Commercial catches terminated in the 1960s for blue and humpback whales, in the 1970s for fin and sei whales, but continued until 1986/87 for minke whales.
[b] The sighting data for any single season are very limited or incomplete, thus it is only possible to average the results over several seasons.
[c] Including a small number of a separate stock of pigmy blue whales.
[d] From aerial surveys and/or land based studies there is evidence of increases in right whale stocks off South Africa and Argentina. Each of these stocks numbers in a few hundreds.

biases in the age determinations, and in any statistics derived therefrom.

Whale sighting. Since whales surface regularly to breathe, it is possible to make estimates based on sighting data. This method was first used by scientists on the *Discovery* in the 1930s, and then from 1965 to 1979, by Japanese scouting boats assisting in whale-catching operations. The subsequent development of line-transect sighting theory (by which rigorous statistical methods are applied to census data collected along lines transecting a given area) has made whale sighting the most accurate estimation method.

Line transect sighting has been used in a series of annual Antarctic cruises since 1977/78, carried out under a program known as the International Decade of Cetacean Research (IDCR). Japan and the Soviet Union have provided the platforms, but the scientists have been drawn from many countries. Each year's operations have been confined to one Antarctic sector of about 60 degrees longitude, so that in 6 years the whole area has been covered from 60 degrees South latitude to the ice edge. While this method has provided the best estimates of whale stocks to date, even these data are not completely accurate because of difficulties in sighting whales and assumptions required for statistical purposes.

Status of the Stocks

Despite the uncertainties associated with the various methods of estimating whale populations, methodical analyses of whale stocks were performed in the 1960s to try to set safe catch limits. These analyses resulted in total protection for blue and humpback whales, and major reductions for other species. Early in the 1970s, total protection was declared for fin and sei whales, leaving minke whales as the only baleen resource open to exploitation.

Table 1 provides the best present estimates of Antarctic whale stocks. In discussing and comparing whale population estimates, it is important to distinguish estimates of the total population, usually obtained from sighting data, and estimates of the exploitable population, usually based on catch statistics. The exploitable population, consisting of whales large enough to warrant being caught, is usually two-thirds of the total population.

Stock estimates, such as those shown in Table 1, are important figures. They can be compared with other estimates, both past and present, to establish and predict population trends (as long as the greater uncertainties of past estimates are taken into account).

Future of Antarctic Baleen Whales

One concern of environmentalists and scientists alike has been whether the depletion of the great whales in the Southern Hemisphere (and elsewhere) has been so great that several of the species might become completely extinct. The verdict on this possibility is not yet in, and will require careful monitoring of population trends. Recent right whale increases documented by careful studies give some basis for guarded optimism. Right whales have been mostly protected, at least under regulations of the IWC, and under some earlier agreements, since the 1930s. Yet, until the 1970s, evidence of any rebuilding was nonexistent. Furthermore, even where there have been local increases, as noted in the footnote to Table 1, the stocks in question still number only in the hundreds.

Japanese Whaling in the Antarctic:

Japan sent an expedition to the Antarctic late last year, declaring that they intended to catch 300 minke whales for scientific purposes. Many environmentalists and member nations of the International Whaling Commission (IWC) accused Japan of using scientific intent as a thin disguise for purely commercial purposes. The IWC had imposed a moratorium on commercial whaling in 1985/86 in the Antarctic, and elsewhere in 1986.

The IWC is a regulatory body, but without real means of enforcing its regulations. However, two domestic United States laws, the Packwood-Magnuson Amendment and the Pelly Amendment can be used to supply coercive power. Both of these laws call for economic sanctions against nations that "diminish the effectiveness" of international fisheries agreements in which the United States participates.

If a nation is "certified" to be undermining an international fisheries treaty, then, under the Pelly Amendment, the United States may embargo marine products from the nation in question. Under the Packwood-Magnuson Amendment, the Commerce Department may reduce fishing quotas in American territorial waters by at least 50 percent for any nation certified to be diminishing the effectiveness of the IWC. While these measures have been available, and threatened, in the past, there has been a reluctance to implement them. Recent events may be changing this practice.

*The resolution for a moratorium on commercial whaling was passed by the IWC in July 1982. Included was an important provision that the IWC make a comprehensive assessment by 1990 to assess the effects of zero catch limits on whale stocks. Japan was one of four countries to lodge formal objections to the moratorium resolution.**

In November 1984, the Japanese and United States governments reached a bilateral agreement. Japan would withdraw its objection to the moratorium providing they be allowed to take whales until the end of the pelagic 1986/1987 Antarctic season and the coastal 1987 season, without the imposition of economic sanctions by the American government. In July 1986, after the U.S. Supreme Court upheld the U.S. government's decision not to impose sanctions, Japan withdrew its objection and notified the IWC that all commercial whaling would cease after the 1987 coastal season.

Days after the final commercial Antarctic whaling expedition had returned to Japan, the Japanese submitted to the IWC a proposal for scientific whaling for the 1987/1988 Antarctic season. The study, in which Japan proposed to take 825 minke and 50 sperm whales as part of a 12-year program, was to contribute to the IWC's mandated "comprehensive assessment" of the world's whale stocks.

According to the August/September 1987 issue of Marine Mammal News, *a newsletter published by Nautilus Press in Washington, D.C., Japan intended to collect such data as sex ratios, migratory factors, pregnancy rates, and age composition of the stocks—to estimate stock size and growth, and to predict trends. Upon completion of the study, whales would be sold to help*

* The Soviet Union, Norway, and Peru also formally objected to the commercial whaling moratorium, although Peru withdrew its objection in 1983. Having lodged their objections within 90 days, these countries are allowed, by rules of the IWC, to set their own quotas and continue whaling.

A second concern is the difficulty scientists have had in understanding whale population dynamics, particularly their response to exploitation. These difficulties have been due in part to the extreme problems in making observations on whales. Much of what is known about whales, particularly in the Antarctic, comes from dead whales on commercial whaling vessels; this must give a distorted picture of the true situation.

Contained within the question of population dynamics is the knowledge that human exploitation is, on an evolutionary time scale, very recent indeed. Thus, it has not been determined what population mechanisms, if any, have been developed by the whales in response to this population reduction.

Even more difficult is the fact that we do not know what mechanisms keep whale stocks in balance with their resources. If food is a limiting factor, then any rebuilding of the great whale stocks is further complicated by interactions between whale species and other species that feed on the same organisms. While it appears that as blue and fin whales were depleted, sei and minke whales increased in numbers, the evidence for this remains unclear. However, there is clear evidence that there have been increases in other krill-eating species, such as crabeater seals and penguins. In fact, the crabeater seals are now the largest krill

Science or Subterfuge?

finance the expedition. According to Alan Macnow, spokesman for the Japan Whaling Association, "not a penny of profits from the sales" would go to commercial interests.

Although the Scientific Committee was unable to reach a consensus on the scientific merit of the Japanese proposal, the IWC recommended that the Japanese government not issue whaling permits. Japan later submitted a revised research proposal, in which only 300 minke whales would be taken in 1987/1988, as part of a feasibility study.

At a special meeting of the Scientific Committee in mid-December 1987, it was agreed that the taking of 300 minke whales would not deplete the population. The majority of the committee, however, found that there was no compelling need to take the whales, and proposed instead that nonlethal methods would provide the information sought by the Japanese.

Despite these and other findings, Japan announced that the committee had "no substantive opposition" to the research plan. The Japanese fleet set sail for the Antarctic on 23 December, 1987.

On the same day, Britain proposed a resolution, stating that "in light of scientific uncertainties" the Japanese should not be allowed to go ahead with its research plans. This resolution was sent out to IWC members as a mail ballot, due back on 14 February, 1988.

The first minke whale was reported to have been taken by the Japanese in early February 1988, before the results of the ballot were collected. On 9 February, the United States Secretary of Commerce certified Japan, invoking the Packwood-Magnuson and Pelly Amendments. By law, President Reagan had 60 days to decide what action to take. Before he could reach a decision, however, Japan had finished its collection of the 300 minke whales.*

Largely because of reduced fish stocks in 1987/1988, Japan had no 1988 fishery allocations in American waters, almost rendering the Packwood-Magnuson ineffective. The only way the amendment could be used as a punitive measure was to deny requests for future quotas. On 6 April 1988, the President denied a Japanese request to harvest 3,000 metric tons of Alaskan sea snails and 5,000 metric tons of Pacific whiting in American waters. Further requests for fishery allocations including Pacific cod, also would be denied "until the Secretary of Commerce determines that the situation has been corrected."

Embargoes were not imposed against Japanese marine products via the Pelly Amendment. This is not surprising since the United States exports twice the dollar volume of marine products to the Japanese as it imports from them ($1 billion versus $500 million); the United States would therefore not be expected to invite trade retaliation by Japan. The President, however, has asked the Secretary of Commerce and the Secretary of State to monitor Japan's whaling practices and report by 1 December 1988. At this time, which should precede the 1988/89 Antarctic research whaling season, the need for trade embargoes would be reconsidered.

Sara L. Ellis
***Oceanus* Intern**

* Tallied on February 13, 1988, the results of the mail ballot requested by the British were: 19 in favor; 6 against; 2 abstentions. Argentina's vote arrived after the tally, bringing the total numbers of votes in favor of the resolution to 20.

consumers in total (page 71). What the impact of such changes will be on whale stock rebuilding remains uncertain.

A Slow Return

In earlier studies, scientists of the International Whaling Commission attempted to estimate recruitment since the beginning of exploitation, and used such estimates to reconstruct estimates of pre-exploitation levels. It is now clear that such reconstructions are dubious at best. It is, however, agreed that recruitment rates are much lower than were assumed or estimated in the earliest analyses of whale stocks. There also is a consensus among whale scientists that the return of the great whale stocks to their pre-exploitation status will be an extremely slow process—to be measured in decades or perhaps even centuries.

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Selected Readings

Brownell, R. L., P. B. Best, and J. H. Prescott, eds. 1986. *Right Whales: Past and Present Status.* 289 pp. Cambridge, U.K. Reports of the International Whaling Commission. Special Issue 10.

Horwood, J. W. 1987. *The Sei Whale: Population Biology, Ecology, and Management.* 375 pp. London: Croom Helm Ltd.

Humpback and Right Whales

Humpback whales are probably more abundant than previous estimates predicted, and right whales are regular members of the whale species in waters along the western Antarctic Peninsula. These results are based on a 1986 cruise of the R/V Polar Duke*, reported in the January 1988 issue of* Polar Record *by Gregory S. Stone of the College of the Atlantic, and William M. Hamner of the University of California at Los Angeles.*

Heavy whaling in the 20th Century may have reduced the Antarctic humpback whale population by as much as 90 percent, while right whales were already considered to be commercially extinct by the time Antarctic whaling began. Presently, humpback whales are seen fairly regularly in Antarctic waters, but there have been very few sightings of right whales. Recent status reports have estimated both Antarctic humpback and right whale populations to be as low as 3,000, or less; in fact, a United Nations Fisheries and Agriculture Organization 1985 report did not consider right whales to be part of the Antarctic cetacean fauna.

The 1986 cruise of the Polar Duke *is one of the few attempts to estimate present populations of Antarctic whales. Whale sighting surveys were performed in the Gerlache Strait and the surrounding bays. From 2 April to 20 April, 1986, 455 nautical miles were surveyed. Two observers were stationed on the bridge of the research vessel. On sighting a whale, small inflatable boats were launched to approach the whale closely while the crew photographed it for individual identification. Humpback whales can be identified by their distinctive pigmentation on the undersides of their flukes and/or distinctive body scars; while right whales have distinctive callosity (areas of hardening or thickening of the skin) patterns on the head and jaws.*

In total, there were 103 humpback and 8 right whale sightings. Using the photographs, 23 individual humpback and 4 individual right whales were identified. Previously, no right whales had been recorded south of 63 degrees South, yet on this cruise they were sighted almost as far south as 65 degrees South. Highest densities for both humpback and right whales were recorded inside bays, probably in response to higher food densities, rather than in relatively open water. Both whale species were seen feeding on krill.

When the photographs of the individually identified humpback and right whales were compared with 3,800 photographs of North Atlantic humpbacks, and 623 photographs of right whales near Valdez Peninsula, Argentina, no matches were found. While these results imply that humpback and right whales of the Antarctic Peninsula do not migrate to the North Atlantic, or the Valdez Peninsula, respectively, further photo-identification studies will be needed to determine where these stocks do migrate. It is likely that these stocks winter off the coast of South America, but it is unknown whether they go to the east or west coast.

The waters that were surveyed by the Polar Duke *have been proposed as a primary site for a krill fishery. Since baleen whales prey heavily on krill, they will be a key component in ecosystem models for krill fisheries. The results of this study—that the abundance of both humpback and right whales on the west side of the Antarctic Peninsula are higher than expected—are therefore crucial to an ecosystem model for the area.*

—SLE

Laws, R. M. 1977. The significance of vertebrates in the Antarctic marine ecosystem. pp. 411–38. In *Adaptations within Antarctic Ecosystems: Proceedings of the Third SCAR Symposium on Antarctic Biology*, G. A. Llano, ed. 1252 pp. Smithsonian Institution: Washington, D.C.

Tonnessen, J. N., and A. O. Johnsen. 1982. *The History of Modern Whaling*. 798 pp. Berkley and Los Angeles: University of California Press.

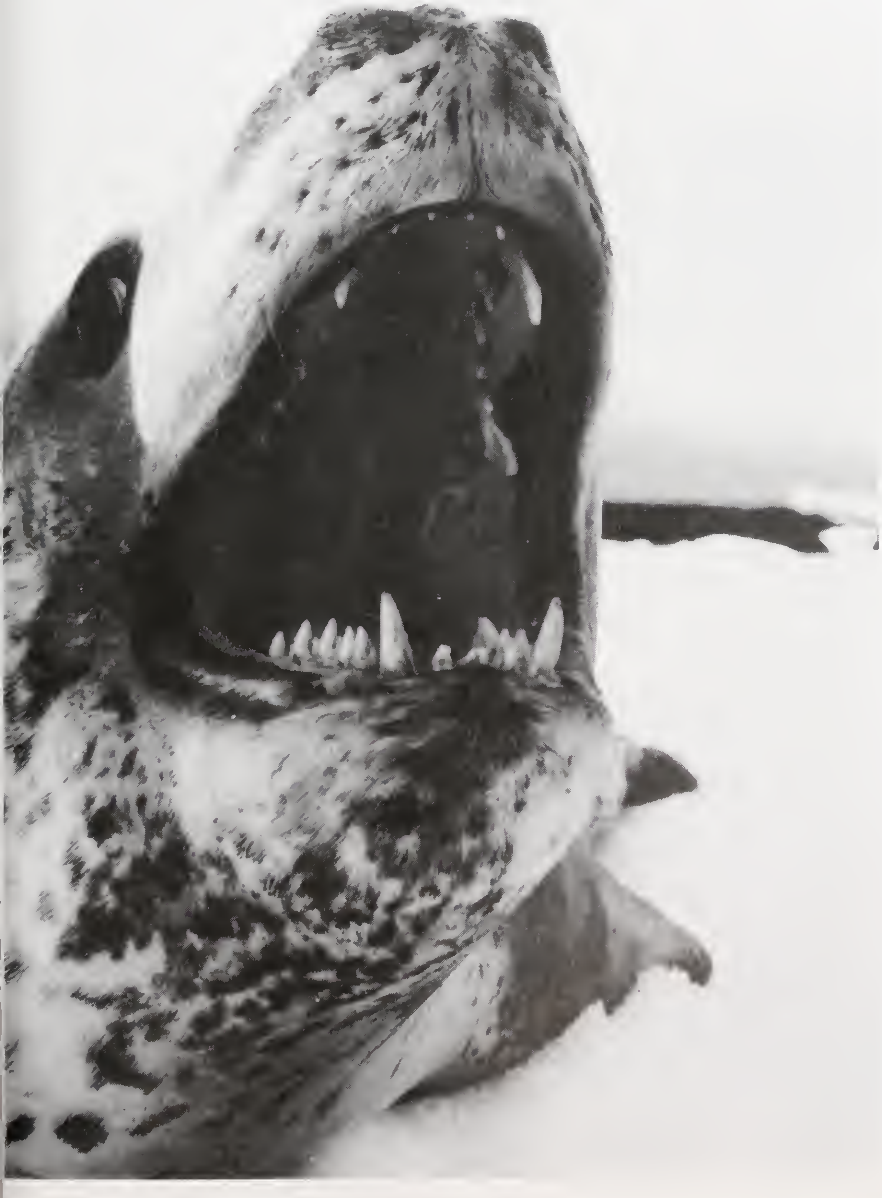
Living Resources:

Seals

by Donald B. Siniff

Six seal species live in Antarctic waters—waters generally considered to be those south of 60 degrees South latitude. Along with whales, seals are the most significant food consumers, with summer bird populations coming next, but at a level much below the marine mammals.

Of the six seal species, five are true, or earless, seals. These are the Weddell, leopard, crabeater, Ross (considered true Antarctic seals), and the elephant seal (considered to be mostly subantarctic in distribution). The sixth is the southern fur seal, which belongs to the sea lion family—the group of seals that have external ears.



Open jaws of a leopard seal. The teeth are well adapted for seizing and tearing flesh. (Photo by S. Stone)

These seals contribute a significant part of the Antarctic vertebrate biomass, particularly since the great whales have declined so dramatically in numbers. R.M. Laws, former director of the British Antarctic Survey, compared the relative biomass of different vertebrate groups in the Antarctic marine ecosystem, estimating the seal species at about 2.8 million metric tons, and the whale stocks at about 6.6 million metric tons.

The four species of true Antarctic seals (the Weddell, leopard, crabeater, and Ross) which occupy the pack ice regions around the Antarctic continent are quite different in their habits and habitats occupied, and none of these species have been exploited to any degree for either their skins or animal products.

Of all the seals, the crabeater seal is the most abundant—and is a specialist in its foraging practices, since it feeds almost entirely on Antarctic krill. If the commercial harvest of Antarctic krill increases, the crabeater seal is the most likely species to be directly affected.

After an initial Norwegian seal venture in 1964, many nations believed world pressure to harvest Antarctic seals would increase. In the late 1960s and early 1970s, several discussions among the Antarctic nations concerned with the potential exploitation of Antarctic seal species led to the Convention of the Conservation of Antarctic Seals, which was signed in 1972, and entered into force in 1978. This convention was unusual because it was adopted at a time when there was no commercial harvest of seals, but only with the thought that sealing might begin. This convention set quotas for the various seal species, and procedures to control the take, if an industry developed.

In the late 1970s, it became apparent that commercial ventures would probably focus on Antarctic krill. Again, there was pressure to develop a conservation convention to protect this important species. The result was the Convention for the Conservation of Antarctic Marine Living Resources (CCAMLR). This convention covers all marine living resources in the Antarctic. It has provisions requiring that the taking of one biological species must not interfere with the normal life history patterns of other species (see also page 59). Both krill and seals, and their interactions, are monitored and studied under CCAMLR.

Crabeater Seal

The crabeater seal occupies the pack-ice region that surrounds the Antarctic continent. Its population size has been estimated to be between 15 and 30 million—it is considered the most abundant seal in the world. At the present time, the crabeater seal is considered to be increasing in abundance—thought to be a reflection of increased food abundance brought about by the decline of whales in the southern oceans.

The crabeater seal forms family groups in the spring, in the pack-ice regions. The groups are composed of a male, female, and pup—occupying a drifting ice flow. The length of time the family group remains together is uncertain, but it is thought to be about 4 weeks, following which time the pup is weaned and breeding takes place.

The crabeater seal feeds almost exclusively on Antarctic krill—also the major food of many of the large baleen whales. This seal species has special lobed teeth which assist it in sifting the krill, small shrimp-like organisms, from the water.

Two predators have played a significant role in the evolution of the crabeater's life history; the killer whale and leopard seal. The killer whale actively seeks crabeaters of all ages, while the leopard seal preys primarily upon newly-weaned pups or animals in their first year of life. This predator pressure is thought to play a major evolutionary role in the crabeater seal's life history patterns, particularly during the mating and pupping season.

The crabeater seal has received recent attention because it would be one of the first species impacted by a significant harvest of Antarctic krill. Measures of feeding activity, general body condition, and other biological parameters have been suggested as measures that could be used to indicate whether commercial harvest was having a significant impact upon the crabeater seal, and in turn, the ecosystem. This seal has therefore been targeted as a species that should be studied and monitored over the long term, so as to predict changes that might be brought about by man's harvest of krill.

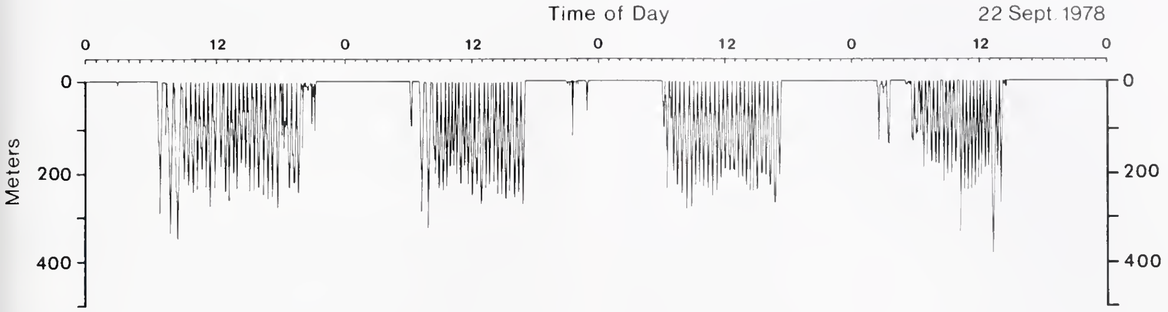
Weddell Seal

The Weddell seal occupies fast-ice environments close to the Antarctic continent, often close to Antarctic scientific bases. Pregnant females begin to come onto the surface of the ice, along predictable annual tide cracks, in late October and November to give birth. The length of the pup's dependency period is between 5 and 6 weeks. Toward the end of this period, females come into estrus and breeding occurs. The adult males occupy underwater territories beneath the cracks in the ice that have provided access to the surface for the females. Breeding occurs under the ice in these regions.

Weddell seals feed primarily on fish, particularly the Antarctic cod and the Antarctic silverfish. Long-term studies have indicated that the Weddell, once it is an adult, returns to the pupping colonies with a high degree of predictability. However, the young animals disperse away from the colony where they are born, and seem to spend the first 4 to 5 years of their life out in the pack ice regions. As they approach maturity, they come ashore into the fast-ice areas where the colonies occur. Once they have moved into a colony as adults, they remain in these areas for annual pupping and breeding.

The population has been estimated at around 800,000, and is basically stable except for some colonies that occur close to Antarctic bases, where killing has occurred in order to feed dog teams.

Since the Weddell seal habitat primarily occurs close to the Antarctic continent, it seems



A portion of a dive record obtained by the research team of Gerald L. Kooyman from a free-ranging Weddell seal. The last day of the record is indicated as 22 September 1978. The original tick marks are equal to 1 hour, and 0 and 12 equal midnight and noon, respectively. (After G. L. Kooyman and co-authors, 1980, J. Comp. Physiol. *138)*

unlikely that commercial ventures exploiting krill or other biological resources will have significant impact on this species. Future exploitation of krill, however, may influence young Weddell seals because of their dispersal characteristics.

The adult Weddell is not impacted by predators—since they remain close to shore in heavy pack ice regions, where access by killer whales and leopard seals is severely limited. Some are taken by killer whales as the ice breaks up in the spring and summer, but this impact on Weddell seal numbers is thought to be small.

Leopard Seal

The leopard seal is the largest of the four Antarctic seal species. They have become rather well known because of their often rather spectacular predatory activities. These seals regularly kill warm-blooded animals—but feed as well on fish, cephalopods, and Antarctic krill. They are well known for their activity around penguin colonies where, in late summer, they prey heavily on young penguins as they go to sea for the first time. Leopard seals often lie along the shoreline waiting for these young, naive birds to enter the water on their way out to sea. They also take young crabeater seals shortly after weaning.

A Weddell seal with an instrument package to monitor the time, duration, and depth of each dive. The data from such instruments have proved invaluable in determining the patterns of seal activity whilst at sea. (Photo by Gerald L. Kooyman)

By nature, the leopard seal is a solitary animal. Little is known about its movement patterns in the Antarctic pack-ice regions. Immature leopard seals are known to congregate regularly on certain

Killer whales surfacing in the Antarctic. Killer whales are major predators of crabeater seals. (Photo by T. G. Smith)

subantarctic islands as they migrate north during the late autumn and winter.

The food of the leopard seal is varied, depending on the season of the year. In the spring (September, October, and November), Antarctic krill seem to be very important. During the mid-summer period of December and January, newly-weaned crabeater seals become important. Then, in late January and February, young penguins become available and are taken extensively. Fish and cephalopods are also taken periodically, and compose about 5 to 20 percent of their diet.

Ross Seal

The Ross seal is the least known of the four Antarctic species. For unknown reasons, it is relatively rare in Antarctic pack-ice waters—although it has been sighted in all pack ice regions around the Antarctic continent, and apparently has a wide distribution. The population has been estimated to be around 220,000. Recent studies by the South African Antarctic Program have indicated that the Ross seal composes up to 15 percent of the seals in a region of the eastern Weddell Sea—the area of highest concentrations of Ross seals.

The reproductive period of this species appears to be in November and December. They feed primarily on squid, and probably have deep-diving capabilities to capture this prey. The reason for this species being rare is simply unknown. The Ross seal has never been harvested by man, and changes in the ecosystem brought about by the past exploitation of whales should have enhanced its food resources. Because of its solitary nature, it would likely not be affected greatly by competition with the other seal species. In future studies, it may be important to consider the Ross seal, because environmental changes causing an increase in numbers would readily be noticed.

Recent Research

Research on Antarctic seal species has mostly focused on the Weddell and crabeater. For the Weddell, the physiology and population ecology have received the most emphasis. The Weddell is particularly good for physiological studies, since they can be instrumented and easily recaptured. Gerald L. Kooyman of the Scripps Institution of Oceanography, and others have done a great deal of research on the physiology of the Weddell seal, using advanced instrumentation to measure physiological parameters associated with the diving abilities of this species. The author and others have described the population ecology of the Weddell seal, using a long-term data base containing records of tagged Weddell seals in the McMurdo Sound area. Immigration, survival, and reproductive characteristics for this population were among the results.

Other nations in the Antarctic scientific community also study seals. These include Britain, South Africa, Australia, Argentina, and Japan. Britain also has an excellent program studying the population status of the southern fur seal. The Argentine program concentrates on the southern elephant seal and southern fur seal in the region of the Antarctic Peninsula. Measurements of pup survival, as well as behavior during the period of lactation, have provided new insights into the status of these species. The Japanese Antarctic program has done work on the Weddell seal off their Syowa Station. This work has concentrated on census and diving characteristics, using depth-of-dive recorders.

No Direct Impacts Predicted

The four true Antarctic seal species have not been impacted directly by activities of man in the Southern Ocean. If indirect effects do occur, it is anticipated that harvest of Antarctic krill will have the most significant influence on the crabeater seal.

Because the true Antarctic seals historically have occupied the pack-ice region, they simply have not been available, to any large degree, for commercial harvest. It seems unlikely that the economics of this situation will change in the near future. It is very probable that the four species of true Antarctic seals will remain relatively untouched, at least directly, by human activities.

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Selected Readings

Bengtson, J. L., and R. M. Laws. 1985. Trends in crabeater seal age at maturity: an insight into Antarctic marine interactions In *Antarctic Nutrient Cycles and Food Webs*, W. R. Siegfried, P. R. Condy, and R. M. Laws, eds., pp. 669–675. Berlin: Springer Verlag.

Croxall, J. P., and L. Hiby. 1983. Fecundity, survival and site fidelity in Weddell seals, *Leptonychotes weddelli*. *J. Appl. Ecol.* 20:19–32.

Hill, R. D., R. C. Schneider, G. C. Liggins, A. H. Schuette, R. L. Elliott, M. Guppy, P. W. Hochachka, J. Quist, K. J. Falke, and W. M. Zapol. 1987. Heart rate and body temperature during free diving of the Weddell seal. *Amer. J. Physiol.* 253:R344–351.

Kooyman, G. L. 1981. *Weddell Seal—consummate diver.* 135 pp. Cambridge, England: Cambridge University Press.

Laws, R. M. 1977. The significance of vertebrates in the Antarctic marine ecosystem. In *Adaptations Within Antarctic Ecosystems*, ed. by G. A. Llano, pp. 411–438. Proceedings of the 3rd SCAR Symposium on Antarctic Biology. Washington, D.C.: Smithsonian Institution.

Laws, R. M. 1984. Seals. In *Antarctic Ecology*. Vol. 2, R. M. Laws, ed., pp. 621–715. London: Academic Press.

Siniff, D. B., I. Stirling, J. L. Bengtson, and R. A. Reichle. 1979. Social and reproductive behaviour of crabeater seals, *Lobodon carcinophagus*, during the austral spring. *Can. J. Zool.* 57:2243–2255.

Testa, J. W., and D. B. Siniff. 1987. Population dynamics of Weddell seals (*Leptonychotes weddelli*) in McMurdo Sound, Antarctica. *Ecological Monographs* 57:149–165.

Living Resources:

The BIOMASS Program

by Sayed Z. El-Sayed

While the news of the depletion of ozone levels over Antarctica has recently captured global headlines, news coverage of the impending depletion of marine living resources in the Antarctic is pale by comparison. Yet, both kinds of depletion have far-reaching ecological and economic implications.

This year is the 10th anniversary of the beginning of the international BIOMASS program. An initial report on BIOMASS, an acronym for Biological Investigations of Marine Antarctic Systems and Stocks, appeared in the Spring 1979 issue of *Oceanus*. It is, therefore, appropriate in 1988 to examine the accomplishments of the BIOMASS program; and to discuss its impact on the conservation of marine living resources of Antarctica in general, and future biological research in the Southern Ocean in particular.

History of BIOMASS

In the early 1970s, as the world seemed poised to begin large-scale harvesting of the rich Antarctic marine living resources, concern over the proper management and conservation of these resources was expressed by members of the scientific community and international agencies and organizations. The concern for the conservation of Antarctic marine resources, and in particular the shrimp-like organism, krill (*Euphausia superba*), stemmed from the fact that several fishing nations were gearing up to harvest these resources. The dwindling stocks of conventional fishes because of excessive fishing, together with the establishment of 200-nautical-mile Exclusive Economic Zones, forced long-distance fishing fleets to hunt for harvest outside national jurisdictions. These factors, together with the human population explosion and an increased demand for more animal protein, led to a search for new sources of marine food, and in particular, the virtually untouched krill stocks.

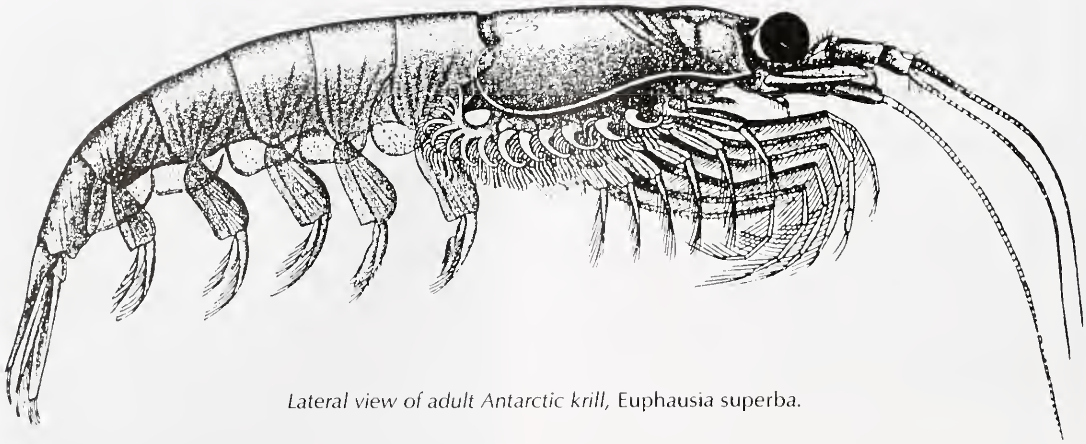
Recognizing that unwise and unregulated past exploitation had decimated the southern fur seal and baleen whale populations, and recognizing krill's key position in the Southern Ocean food web and its impending exploitation, the Scientific Committee on Antarctic Research (SCAR), a committee of the International Council of Scientific Unions (ICSU), foresaw a need for substantial expansion of scientific research on Antarctic marine ecosystems. SCAR, which has had the responsibility of initiating, facilitating, and coordinating international scientific programs from its inception in 1958, established a group of experts in 1972 to address this need.

By 1976, a proposal had been developed for international cooperative studies on the living resources of the Southern Ocean. The proposal became known by its acronym, BIOMASS.

The primary goal of the BIOMASS program has been to build a sound scientific foundation on which to base future management decisions. Because of the pivotal role of krill in the Antarctic food web, and because of its potentially significant contribution to world protein supplies, krill studies have played a key role in the BIOMASS program (although organisms at higher food-chain levels, such as fish and birds, were also included).

The austral summer (December, January, February) of 1980/81 was chosen for the First International BIOMASS Experiment (FIBEX), in which 13 ships from 11 nations participated in the largest biological oceanographic expedition ever mounted in the Southern Ocean. The Second International BIOMASS Experiment (SIBEX), Phase I (1983/84) and Phase II (1984/85), was the final collaborative field effort of this ambitious 10-year program.

Seasonal and annual variations in the distribution and production of krill were studied in three relatively small areas that are noted for their high krill concentrations: Bransfield Strait/Elephant Island (Atlantic sector), Prydz Bay (Indian sector), and 60 degrees East (Pacific sector) (Figure 1).



Lateral view of adult Antarctic krill, Euphausia superba.

Krill Research

In Antarctic krill research, as in most science, the work often has been fraught with unexpected turns and complexities, yet has sometimes produced surprising results. This was true for each of the four types of work we pursued.

Estimation of stock size. One of the most vexing problems that faced krill investigators was the determination of the size of krill standing stocks. Such stock assessment lies at the heart of any meaningful management practice.

Past attempts to estimate total krill standing stocks indirectly (from the decline in large baleen whale stocks) or directly (by plankton-net sampling) were proven to be unsatisfactory. Great discontinuities in the distribution and swarming behavior of krill, the relatively small areas in which sampling was conducted, and the diverse methods used in estimating standing stocks were responsible for the high variance of krill stock estimates. According to these estimates, krill stocks could have ranged between 200 million to 3.5 billion metric tons!

In recent years, the introduction of quantitative acoustic techniques for stock assessment have shown great promise, although not without problems. Because of the differences in the density of krill tissue and sea water, and in the speed of sound through these two media, krill reflect sound. The proportion of incident sound energy reflected (known as target strength) depends primarily on the acoustic properties of krill tissue, the ratio of the animal's length to the acoustic wavelength, and the orientation of the animal with respect to the incident beam. The target strength of krill is sufficiently high to allow them to be generally detectable by conventional ultrasonic echosounders when aggregated in the upper few hundred meters. Detectability problems arise when krill are shallower than about 10 meters (above the transducer or lost in the surface clutter).

Other problems are due to the difficulty in distinguishing between echoes from krill and other organisms frequenting the same depth range. To solve this problem, acoustic targets need to be identified periodically by aimed fishing. Fortunately, the dominance of *E. superba* in the near-surface waters of the Southern Ocean, the homogeneity of krill concentration, and the species' characteristic aggregation behavior all serve to make identification less of a problem than for pelagic species in lower latitudes.

Despite these problems, acoustic surveys offer the greatest potential for improving estimates on *E. superba* standing stock. Between January and March 1981, joint krill hydroacoustic surveys during FIBEX produced an estimated krill biomass of 250 to 600 million metric tons. Other independent estimates of overall krill biomass amounted to 500 to 700 million metric tons or even more—an estimate that generally supported the FIBEX numbers. The FIBEX survey represents by far the most concerted attempt to assess krill acoustically to date, and provided an insight into the methodological problems involved in the collection and joint analysis of acoustic data.

Stock identification. As a result of the observations on krill distribution made during FIBEX and SIBEX, we next examined whether local krill concentrations are essentially isolated from one another, or whether substantial intermixing occurs. These inferences have profound implications, as they will ultimately determine to what extent local and/or regional concentrations can be treated as separate stocks for management purposes.

The conventional methods of tagging and of relying on morphometric measurements, successfully used by fishery biologists in identifying other discrete management stocks, are not applicable to krill. Realizing this, investigators have resorted to alternative methods of separating krill stocks.

A useful and widely-used method to look at the local population of a species has been electrophoretic analysis of the variations in the

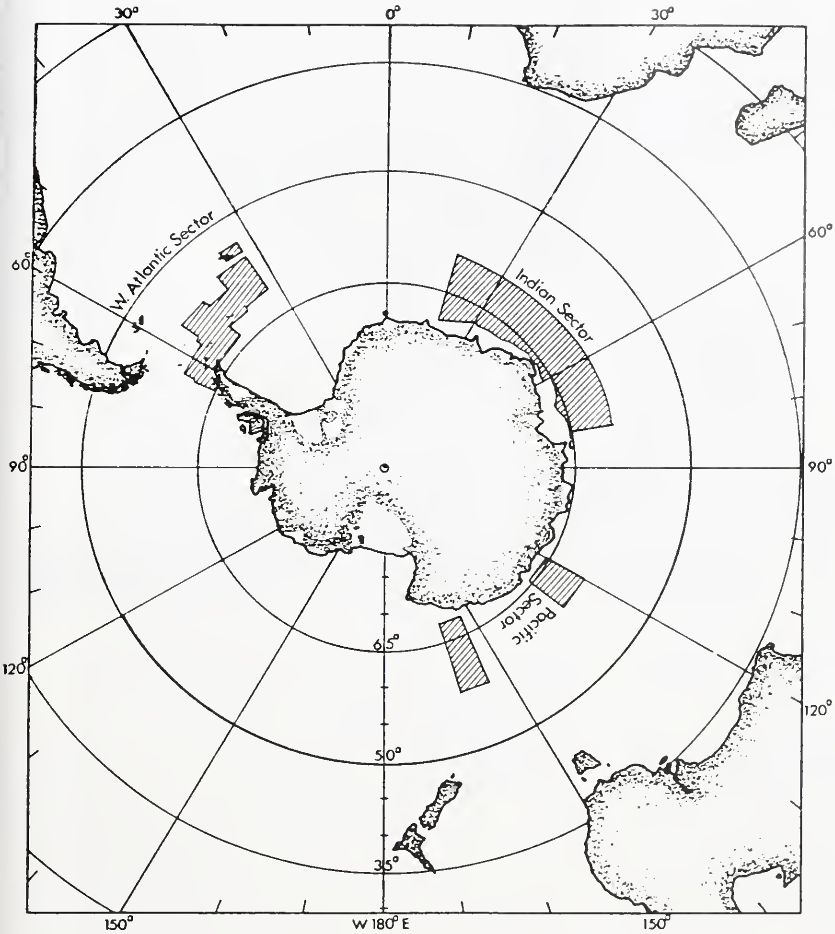


Figure 1. The three study sites (shaded areas) for research on seasonal and annual variations in the distribution and production of krill. Sites were chosen because of high krill concentrations.

structure of enzymatic protein. Where populations of an animal are isolated for generations, processes may have caused differences in the gene structure at locations that are responsible for the coding of certain proteins.

The electrophoresis technique has provided valuable information about genetic variation in natural populations in a way that would have seemed impossible only a few years ago. A tissue sample is first prepared from each of a series of individual organisms. Each sample is then applied to a uniform, porous gel, often one made of starch, and an electric potential is applied across the gel. Within the gel the many proteins from the tissue sample migrate along the electric field for different distances, depending on their individual electric charges. When the proteins are separated and arranged in this fashion, the portions thought to exhibit important differences between different populations can be examined.

Early electrophoretic analysis of krill suggested the existence of at least two discrete krill populations in the Antarctic Peninsula region. More recently, samples of krill collected from locations in the Weddell Sea, Scotia Sea, around the Antarctic Peninsula, and near Prydz Bay (in the Indian sector of the Southern Ocean) indicated that they were all from a single breeding population. Contradictions remained. Despite the considerable progress made in recent years, the successful separation of individual krill stocks (by genetic or other means) remains elusive and requires further research.

Age determination. It is now well established that the traditional method of determining krill age (by examining the length frequency distribution of catches, regarding the peaks in the histogram as year-classes) is fraught with error. This is largely due to the observations made by the late Mary Alice McWhinnie, who showed that mature krill may shrink in body size as an over-wintering strategy. This could result in the overlapping of successive year classes of mature krill. It also has been suggested that there is a

regression of external sexual characteristics during winter. Drawing on his background in entomology, where for years he has been studying aging in the fleshfly (*Sarcophaga bullata*), George Ettershank of Monash University (Australia) succeeded in using lipofuscin (also called age pigment) to estimate krill age. Lipofuscin accumulates as a consequence of metabolic activity, and its assay is thus a measure of the cumulative metabolic activity of an organism. Although there appears to be a reasonable agreement between physiological and chronological age, and results of the lipofuscin assay independently confirm that krill may live as long as 7 years, the technique, although more reliable than traditional methods, still requires refinement.

Food chain studies. Research results in the last 2 decades have caused an almost complete revision of our concept of the Antarctic food chain. Much of this revision concerns the lower end of the food chain—the species forming the food base for krill.

The relation of krill to its food base has occupied much of the attention of krill biologists. Until the early 1970s, the herbivorous nature and food selectivity of krill seemed well established. Later, it was demonstrated that krill are omnivorous; and using electron micrographs of krill filtering appendages, researchers showed that the krill filtering basket is capable of retaining nanoplankton (organisms between 2 and 20 microns—1 micron = .0001 centimeter) with 30 to 40 percent efficiency. This changed the concept of *E. superba* as an omnivore feeding mainly on large diatoms, and substantially expanded the food resources available to krill.

Interest in the role played by the nanoplankton in krill feeding stimulated research in another even more important direction—in assessing the role of the nanoplankton and the picoplankton (smaller than 2 microns) in the Antarctic food web. In contrast to net phytoplankton (organisms larger than 35 microns), which in the past have received considerable attention and form the basis of the classic food chain (diatom → krill → whale), the contribution of the nanoplankton and picoplankton to the standing crop and primary production have, until recently, been overlooked. It was not until *USNS Eltanin* Cruise 51 (early 1972) that one of my former students, Roger Fay, was the first to show that nanoplankton contribute about 70 percent of the biomass and primary productivity of the Ross Sea. More recently, our research effort in the Atlantic and Indian sectors of the Southern Ocean has convincingly demonstrated that these nano- and picoplankton could be responsible for 70 percent of the standing crop and about 90 percent of the primary production of the Antarctic waters. Although the larger cells are taken more efficiently, in addition to the classic food chain, a complex food web, consisting of pico-, nano-, and micro-plankton-sized components, is now emerging as the new paradigm.

What Lies Ahead?

The BIOMASS program was the first major international collaborative effort to study the Antarctic marine ecosystem, and to provide the necessary information for the wise management of Antarctic marine living resources. BIOMASS marked the end of individual national expeditions, and began the era of well-coordinated, multi-ship, multi-national expeditions. As a result of BIOMASS, a high degree of scientific cooperation and camaraderie has developed among the Antarctic community. This is best exemplified by the data-analysis workshops (15 so far), where scientists from varied backgrounds have agreed to pool their unpublished data for communal analysis and joint publication of the results. With the successful completion of FIBEX and SIBEX, and the establishment of the BIOMASS Data Center (housed within the British Antarctic Survey in Cambridge, England), the program has now entered a new phase of data analysis and data interpretation.

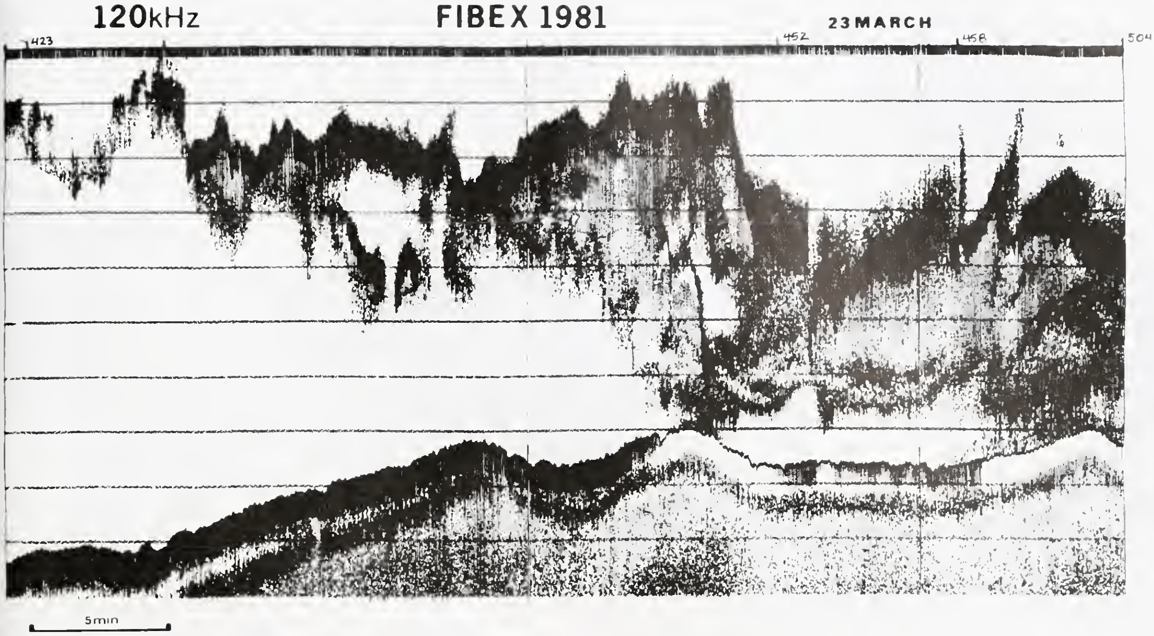
Like all working groups within SCAR, however, the BIOMASS program has a definite charge and a finite lifespan. Following the final analysis and evaluation meeting in 1990 in Bremerhaven, West Germany, BIOMASS will end. Other groups and programs will assume responsibility for the stewardship of the marine resources in the Southern Ocean.

The nongovernmental SCAR will continue to play a major role in facilitating international cooperation in the Southern Ocean ecology and related fields. This has led SCAR, with its long experience of coordination of such research, to establish (jointly with SCOR) the SCAR Group of Specialists on Southern Ocean Ecology, and charge it with identifying important fields of research in Antarctic marine ecology and proposing cooperative studies. Another SCAR group is the Group of Specialists on Antarctic Sea-Ice Zone, whose 10-year program for an international collaborative study includes a biological component.

The third group is the governmental organization, CCAMLR, which has the mandate to conserve the living resources of the Antarctic within the context of the ecosystem (see also page 59). CCAMLR has implemented a monitoring study, and has adopted several conservation measures. It has also established a working group on krill to review and evaluate new research applications to krill abundance and distribution assessment.

There is, however, a need for cooperation between SCAR and its subsidiary bodies and CCAMLR on key research activities. The SCAR/ BIOMASS community has developed a level of competence and expertise capable of advancing basic scientific understanding of the Antarctic marine ecosystem and can make a valuable contribution to CCAMLR.

It is only through such cooperation that the international scientific community is able to improve man's understanding of the world ocean



A patch of krill northwest of Elephant Island, as shown on the 120 kiloHertz system. Depth marks are at 20-meter intervals, time scale at lower left indicates ship's speed. (Macaulay and Mathisen, 1981).

and, at the same time, develop a sound ecological strategy for the exploitation and conservation of its resources. The impending large-scale harvesting of the Antarctic marine living resources, coupled with the urgent need for accurate knowledge about the Southern Ocean ecosystem, are compelling reasons for the heirs of BIOMASS to forge ahead with similar worthy programs.

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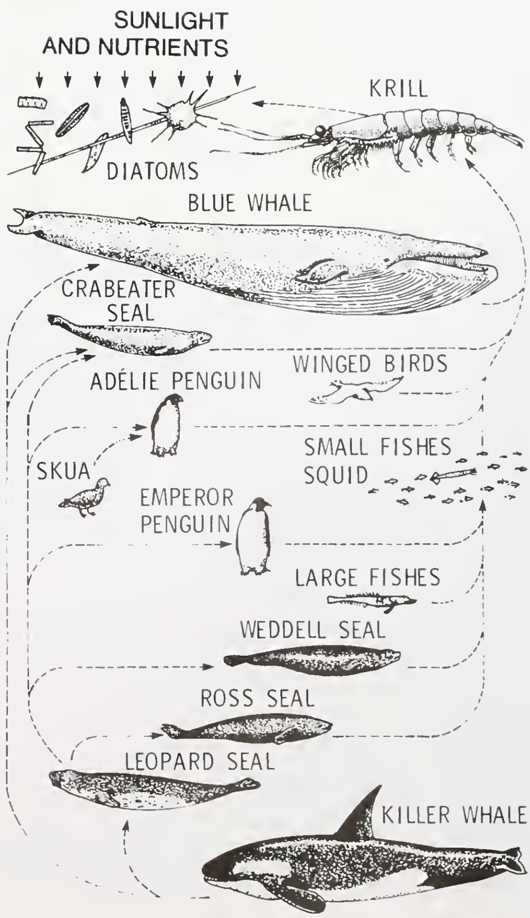
References

El-Sayed, S. Z., ed. 1977. *Biological Investigations of Marine Antarctic Systems and Stocks.* (Vol. I), 79 pp. Cambridge, England: Scott Polar Research Institute.

George, R. Y., Convenor 1986. The biology of Antarctic krill (Euphausia superba). Journal of Crustacean Biology 4: 1–337.

Laws, R. M., ed. 1984. *Antarctic Ecology* (Vol. 2), 505 pp. London: Academic Press.

Walton, D. W. H., ed. 1987. *Antarctic Science.* 280 pp. Cambridge, England: Cambridge University Press.



At right, a representation of the Antarctic food chain.

Antarctic Logistics

by Alfred N. Fowler

In the world of science support, the term *logistics* usually refers to transport and supply functions. In Antarctica, the term is more broadly defined. It includes not only getting there and back, but also transporting everything needed to live and work in a remote area of 14 million square kilometers—twice the size of Australia—where there is no indigenous human population.

The potential user or provider of Antarctic logistics must be dedicated to the principles of environmental protection. Antarctic research is no longer a matter of exploring unknown territory, or of conquering nature by extraordinary human endeavor and grit. Today, the principles of society, such as industrial codes and community behavior that prevail in lower latitudes, also prevail in Antarctica. When planning Antarctic activities on this remote continent, all of society's standards of occupational health and safety, prudent risk management, order and discipline, and of course, environmental protection, must be taken into consideration.

Logistics and the Antarctic Treaty

The Antarctic Treaty System (ATS) has made science and support in Antarctica international. The system has evolved as the original treaty (see page 11) has been overlaid by recommendations of consultative meetings, implementing actions (such as the U.S. Antarctic Conservation Act of 1978) taken by the treaty nations, and two spin-off conventions—the Conservation of Antarctic Seals, and the Conservation of Antarctic Marine Living Resources. As 1991, the 30th anniversary of its ratification, approaches, the ATS is alive and well. Consequently, the prospective user or provider of logistics enjoys freedom of access to the continent, and an absence of national boundaries—assured by the treaty.

Questions concerning Antarctic logistics have been formally addressed at biennial meetings of the Scientific Committee on Antarctic Research

Above, LC-130 ski-equipped airplane off-loading equipment and supplies for a United States field camp. The LC-130 is a four-engine turboprop transport plane that provides the backbone of U.S. transportation within Antarctica. Introduced to the Antarctic program in 1960, the LC-130 runs the bulk of the United States' air service between McMurdo Station and New Zealand. (U.S. Navy photo by Jamie Leitzel)

(SCAR), an international forum. Dating from activities during the International Geophysical Year (IGY) in the late 1950s, SCAR is a standing scientific committee of the International Council of Scientific Unions (ICSU). The SCAR Working Group on Logistics has met about 20 times and has sponsored two symposia on Antarctic logistics, covering virtually every aspect of facilities, utilities, vehicles, communications, energy and fuel, transport, equipment, shelter, clothing, health care, supply, provisioning, and safety in Antarctica.

The presence of permanent Antarctic stations today is an expansion of the original IGY installations of 30 years ago. The treaty nations are identified on page 14. Note that nations with consultative (voting) status are generally those with active programs "on the ice," including stations occupied year-round. Table 1 (page 85) is a list of the wintering stations; the locations of several are shown on page 15.

Governments and government-operated programs have performed fairly well in the area of Antarctic logistics. The track record reflects a good measure of international cooperation and coordination. But times are changing. As we approach the 1990s, several more nations are expressing interest in becoming part of the treaty system. There are places, particularly off the north end of the Antarctic Peninsula, that are starting to get crowded. For example, on King George Island, there are now seven wintering stations within a radius of 25 kilometers.

Recently, there has been a large increase in tourism, private expeditions, and other so-called "non-governmental activities." Tour ships operating out of South America take a few thousand tourists to see and visit the stations in the peninsula area each summer, up from a hundred or so just a few years ago. Commercial operators are flying groups of mountaineers and adventurers to the interior, and large, long-range commercial sightseeing overflights may resume. Environmental organizations have begun operating wintering camps and ship expeditions to Antarctica.

Environmental Protection

Environmental protection, the first commandment of Antarctic logistics, is an extension of the principles of the Antarctic Treaty, and the recommendations adopted as a result of the consultative meetings. The pertinent body of these recommendations appeared in 1964 and is known as the Agreed Measures for the Conservation of Antarctic Fauna and Flora. The United States ratified these in the form of Public Law 95-541, the Antarctic Conservation Act of 1978. The law provides that the Director of the National Science Foundation (NSF) shall prescribe regulations, designate specially protected areas, and issue permits authorizing acts otherwise prohibited by the law. Any U.S. citizen in Antarctica, and any person in Antarctica as a participant in U.S. government activities, is subject to the regulations. The law prohibits taking native animals or birds, entering into special areas, or introducing nonindigenous species into the Antarctic. In the United States, it also is unlawful to have, sell, import, or export Antarctic mammals or birds. For each of these otherwise unlawful acts, the phrase "unless authorized by regulation or permit" applies.

In 1979, the National Science Foundation

McMurdo Station, lit up for the austral winter. (U.S. Navy photo, courtesy of NSF)

published a booklet presenting the law and its implementing regulations. It provides 46 pages of fine print, maps of special areas, and permit application forms. Experience has shown that problems persist in educating people about environmental protection in general, and the provisions of the U.S. law in particular, as well as the resulting difficulties in enforcement. For example, the law prohibits taking native animals or birds. "Take" means to harass, molest, harm, pursue, hunt, shoot, wound, kill, trap, or capture, or to attempt to engage in any of these. Therein lies the rub. Tourists are curious about penguins, and often have the urge to see them up close. Similarly, they are attracted to seals, although to a somewhat lesser extent. These species seem to have no natural fear of humans. They can be easily approached and sometimes their behavior, especially in the case of penguins which exhibit curiosity of their own, contributes to situations that evolve into an unlawful "taking."

Possible conflicts are enhanced by the geography. The vastness of Antarctica is dominated by ice sheets, the surface of which comprise a huge cold desert. Only 2 percent of the continent, primarily along or near the coastal areas, presents exposed rock and soil. As a result, human activity competes directly with the native flora and fauna for these few ice-free sites. Moreover, the conduct of scientific research, which (before the recent surge of tourism) has been the principal activity in Antarctica for 30 years, necessarily focuses on the same 2 percent of the continent. Therefore, even though the magnitude of man's activity in Antarctica is minute with respect to the size of the continent, these factors magnify and concentrate the risk of environmental impact.

The provider or user of logistics in Antarctica often uses boats, over-the-ice vehicles, helicopters, or airplanes. The use of a helicopter, for example, in the close support of a science field party or even as a reconnaissance or survey platform, may disturb birds or mammals. Boating and diving operations, or the preparation and maintenance of runways or skiways, present a similar risk.

Supporting Science in Antarctica

The policy of the United States is to maintain and strengthen the Antarctic Treaty System, and to continue support of the U.S. Antarctic Program at a level providing an active and influential presence. This policy supports a range of U.S. national scientific, political, and environmental interests in that area.

In terms of logistics, the U.S. national program operates permanent stations in the interior at the geographic South Pole, and at coastal sites at McMurdo Station on Ross Island in the southwest corner of the Ross Sea, and at Palmer Station on Anvers Island off the west coast of the Antarctic Peninsula. McMurdo Station is the U.S. logistics hub, the terminal for both airlift and sealift, and the bulk fuel and supply storage site that make possible our operation of the station at South Pole. Also, from McMurdo temporary stations and major field camps have been operated in various locations—from the peaks, glaciers, and dry valleys of the Transantarctic Mountains and the high-cold plateau of East Antarctica, to the Ross Ice Shelf and high snow accumulation areas of West Antarctica.

The total U.S. summer population is about 1,400, including at various times nearly 300 scientists, 700 U.S. Navy, and 500 contractor and other support personnel. Presently the U.S. Antarctic Program spends about $13.5 million on science grants, and $111.3 million for procurement, construction, and logistics. Of the latter amount, $21 million is for ship and aircraft time, and other activities directly in support of science projects. Thus, the total amount spent for science is about $34.5 million, or about 28 percent of the cost of the total program.

In the most recent presidential directive, the policy of the U.S. national program—including logistic support activities—was reaffirmed. It continues to be funded and managed as a single package by the National Science Foundation. Through interagency agreements with NSF, the Department of Defense, (primarily the U.S. Navy), and the Department of Transportation (U.S. Coast Guard) provide reimbursable logistic support, such as air and ship operations as requested by NSF.

The foundation is charged with managing the program in a manner that maximizes cost effectiveness and return on investment, and to this end is encouraged to use commercial support. A contractor provides facilities construction, operation, and maintenance, plus operation of a research vessel, laboratories, and so on. The U.S. Navy continues its important support role, especially in the operation and maintenance of both fixed-wing and helicopter aircraft. Similarly, the annual resupply of McMurdo Station by cargo ships depends on the opening of a channel through the sea ice by one of the U.S. Coast Guard polar icebreakers.

Emphasis on Air Support

When one compares the scope of U.S. operations and logistics in Antarctica with that of other nations, the striking impression is the large extent of the interior of the continent that can be reached by Americans. Several countries have more stations (with the Soviet Union leading both in total number and in geographic spread), but no other country is better able to reach a greater extent of the interior, or to better support projects at interior sites. Others in Antarctica, again the Soviets are an example, have a superior shipborne research capability. NSF via its contractor leases a 4,500-horsepower, 219-foot ice-strengthened research vessel, *Polar Duke*, that also is used for logistic support of its Palmer Station just off the Antarctic Peninsula. *Polar Duke* provides a research platform that cruises in the vicinity of the Peninsula. Looking to the future, the foundation is seeking a research vessel with icebreaking capability for year-round research in Antarctic waters not readily accessible to *Polar Duke*.

The long-range capabilities of the ski-equipped LC-130 airplane have given the United States the advantage in support of projects in the

Plane Restored, Plane Lost

The U.S. Antarctic logistics program had hoped to have eight LC-130s in service this year for science and cargo missions, but lost one plane while trying to retrieve another that was buried under 30 feet of snow after crashing more than 16 years ago.

On 8 December 1987, an LC-130 with 11 U.S. Navy crewmen aboard crashed while carrying parts for use in repairing the plane lost 16 years before. Two crewmen were killed in the crash as the plane burned on impact. Several of the nine other crewmen received major injuries.

The National Science Foundation, describing the ruined LC-130 as "our only science airplane," said air logistics for the rest of the season would be constrained. Photography missions were cancelled, and various data gathering efforts rescheduled.

The loss of the plane overshadowed a tremendous engineering accomplishment. On 10 January 1988, the LC-130 that was dug out of the snow at a site in East Antarctica—refitted with overhauled engines and propellers—made a flight of nearly 800 nautical miles (some 5 hours) to touch down on the ice "skiway" at McMurdo Station.

After inspection and further work, it flew on to Christchurch, New Zealand, on 16 January for further repairs. It was estimated that the cost to recover and to restore the plane will run in the neighborhood of $10 million. A new LC-130 costs approximately $35 million.

—PRR

"Juliet Delta 321" being dug out of the snow after having crashed more than 16 years ago. (U.S. Navy photo, courtesy of NSF)

interior. Seven of these remarkable machines (see also box on this page) are dedicated to the U.S. Antarctic Program, and are operated for the National Science Foundation by the Navy's Antarctic Development Squadron Six (VXE-6).

The LC-130 is a four-engine, turboprop plane permanently configured with selectable ski or wheel landing gear. The LC-130 can carry 12,200 kilograms (27,000 pounds) of cargo, including passengers, from McMurdo to the South Pole Station (728 nautical miles), offload, and then return to McMurdo without refueling. For another example, the 2,100-nautical-mile trip between Christchurch, New Zealand, and McMurdo Station is completed in about 8 hours with a payload of about 6,800 kilograms (15,000 pounds). In 1987, one of the NSF-owned LC-130s flew a rescue mission from McMurdo to Sanae Station on the opposite side of the continent and back—a 4,200-mile trip that was made in 17 hours with one refueling stop at the South Pole on the return leg.

To support science near McMurdo Station and in the ice-free valleys of southern Victoria Land, UH-1N helicopters are used. VXE-6 operates six of these twin turbine UH-1N helicopters. They can carry a payload of 730 kilograms (1,600

pounds), including up to five passengers over an operating radius of 185 kilometers (100 nautical miles). These aircraft have recently been augmented by Twin Otters on skis operated by commercial contractors. Surface-effect vehicles also have been successfully tested for Antarctic use. All of these developments, together with the use of a variety of modern tracked vehicles, have long since rendered obsolete the use of dog sledding in Antarctic logistics.

Field Camps

Using the LC-130 and the helicopters, the United States has established and supported many remote field camps. The largest of these sustained a population of about 70 science and support personnel for a summer operating season of about 100 days. Helicopters operated at such a camp greatly increase the mobility and range of the field work. The helicopters are either ferried to sites close to Ross Island or are loaded aboard the LC-130s for positioning at more distant camps.

For these camps, thousands of gallons of aviation fuel are needed at the camp site—together with pumps, filtering equipment, and other materiels required to efficiently operate and service the aircraft. Operational weather analysis and forecasting, telecommunications, health care, and aircraft maintenance and supply support must also be provided at such camps—along with shelter, power and heat generation, food service, and enough water to supply indoor plumbing, showers, and a laundry.

Fuel

Fuel! If you contemplate being in Antarctica, and can satisfy transportation needs to and from the area, then the next most critical need is fuel. For example, 70 percent of all the fresh water on Earth is in Antarctica, but none of it is available to drink without the fuel to melt it. If one wants more water than just barely enough to sustain life, one must think in terms of fuel needed to melt snow—roughly 1 gallon of fuel produces 35 gallons of water, depending on the efficiency of the system. Desalination water plants using waste heat from power generation are, of course, used at coastal stations.

The fuel supply systems for the U.S. Antarctic Program improved markedly after the acquisition of the turboprop LC-130 airplanes and the disappearance of airplanes that were powered by internal combustion engines. Consequently, the United States no longer needs to store or handle high octane aviation gasoline at its facilities. Considering the abnormal extremes in fire hazards on the ice, this is a significant change in program logistics.

The fuels used in large quantities for power generation; heating; and vehicle, equipment, and aircraft operation, are all diesel- or kerosene-type distillates. Presently, there are two basic fuels: Diesel Fuel-Arctic (DFA) and JP-4, the aircraft fuel. These products are virtually identical. Studies are underway to establish the specifications for a single, multi-use fuel, and to determine what adjustments will be needed in the various engines so that the more than 9-million-gallon-capacity system can be managed without segregation of products. Another feature of modern fuel handling is the near elimination of the need to use 55-gallon steel drums. A full drum of fuel weighs 450 pounds; handling one in the snow and the cold can be a real drain on the human spirit. We can thank the LC-130 once again for the ability to transport and pump bulk quantities of fuel. The integral wing tanks of the aircraft can be used, or a large 3,500-gallon fuselage tank can be installed in the cargo compartment. Large bladders of 10,000- and 25,000-gallon capacity can be rolled and folded up when empty and airlifted to a remote site, deployed, and filled with fuel hauled and pumped by the LC-130. In addition, 500-gallon drums mounted on pallets can be moved as cargo.

Safety and Antarctic Logistics

The extreme fire hazard in Antarctica has been mentioned. Humidity is naturally very low and the use of heat in life support drives it even lower. Shelters, buildings, tents, bedding, and all flammable materials tend to be tinder dry. Everything seems to be charged with static electricity, while the provision of effective grounding in a snow and ice environment is nearly impossible. The ability to fight a fire with water is almost always out of the question. The prevalence of high winds adds to the danger. If that is not enough, consider also the likelihood that drifted snow may block windows or other emergency exits from shelters when disaster strikes.

Logistics Lessons Learned

The following are a few comments about logistics lessons learned in the U.S. Antarctic Program, and the author's perception of some of the fundamental ways we should think about Antarctic logistics:

- *Potential users and providers of logistics in Antarctica should not undertake the testing and evaluation of new or prototype equipment on the ice. In the interest of efficiency, safety, and economy, only proven off-the-shelf equipment should go south.*

- *In a similar way, experience has taught us that the practice of logistics in Antarctica should not be used for training of apprentice workers. The unit cost of carrying on any activity in Antarctica is very high. Each activity center, camp, or station has its own life-support system that requires a staff for operation and maintenance. Growth of a station tends to be accompanied by a loss in net productivity and return on investment. Therefore, only the best qualified, experienced practitioners should be assigned to each logistical job.*

- *Science and support projects that are part of*

Table 1. Stations Operating in The Antarctic, Winter 1987.

Argentina
Belgrano II, 77°52′S, 34°37′W
Orcadas, 60°44′S, 44°44′W
Esperanza, 63°24′S, 56°59′W
Marambio, 64°14′S, 56°38′W
San Martin, 68°08′S, 67°04′W
Jubany, 62°14′S, 58°40′W

Australia
*Macquarie Island, 54°30′S, 158°56′E
Mawson, 67°36′S, 62°52′E
Davis, 68°35′S, 77°58′E
Casey, 66°17′S, 110°32′E

Brazil
Comandante Ferraz, 62°05′S, 58°23′W

Chile
Capitán Arturo Prat, 62°30′S, 59°41′W
General Bernardo O'Higgins, 63°19′S, 57°54′W
Teniente Rodolfo Marsh, 62°12′S, 58°54′W

West Germany
Georg von Neumayer, 70°37′S, 8°22′W

France
Dumont d'Urville, 66°40′S, 140°01′E
*Alfred-Faure, 46°26′S, 51°52′E
*Martin-de-Vivies, 37°50′S, 77°34′E
*Port-aux-Français, 49°21′S, 70°12′E

India
Dakshin Gangotri 70°05′S, 12°00′E

Japan
Syowa, 69°00′S, 39°35′E
Asuka, 71°32′S, 24°08′E

New Zealand
Scott Base, 77°51′S, 166°45′E
*Campbell Island, 52°33′S, 169°09′E

China
Great Wall, 62°13′S, 58°58′W

Poland
Arctowski, 62°09′S, 58°28′W

South Africa
Sanae, 70°18′S, 02°25′W
*Marion Island, 46°52′S, 37°51′E
*Gough Island, 40°21′S, 09°52′W

Britain
*Bird Island, 54°00′S, 38°03′W
Faraday, 65°15′S, 64°16′W
Halley, 75°35′S, 26°40′W
Rothera, 67°34′S, 68°07′W
Signy, 60°43′S, 45°36′W

United States
Amundsen-Scott, 90°S
McMurdo, 77°51′S, 166°40′E
Palmer, 64°46′S, 64°03′W

Soviet Union
Mirnyy, 66°33′S, 93°01′E
Novolazarevskaya, 70°46′S, 11°50′E
Molodezhnaya, 67°40′S, 45°50′E
Vostok, 78°27′S, 106°51′E
Bellingshausen, 62°12′S, 58°58′W
Leningradskaya, 69°30′S, 159°23′E
Russkaya, 74°46′S, 136°51′W

Uruguay
Artigas, 62°11′S, 58°51′W

* Stations north of 60°S

the U.S. Antarctic Program enjoy an important advantage that many other national programs in Antarctica lack: the opportunity to use the entire summer season, without spending the winter. This is possible because of a reliable air link. There are no conventional airfields with hard surface runways for wheeled long-range aircraft on the continent. The use of the LC-130 on skis makes it possible for passengers to be airlifted to McMurdo during the morning twilight of late winter (in August). In 1986 and 1987, this capability was used to position scientists and their equipment at McMurdo for observations and analysis of the seasonal stratospheric ozone depletion phenomenon. For most of the scientific stations in the Antarctic, including Palmer Station, there is no such air link. Ship access to these stations is possible only during the second half of the summer. Field work at or near such stations must either be compressed into the ship-access season or else be designed to include wintering. For many key personnel, such as research scientists with obligations at academic institutions, this presents an intolerable situation. To make matters worse, even when a project can be designed to fit the compressed ship-access season, the participants also must be burdened with the lengthy sea voyages to get there and back. Today's observer of the Antarctic scene may notice that the tourism industry may be providing the stimulus to establish additional air links to Antarctica where the science programs of various nations have not. So be it. Under the principles of the treaty, tourism is recognized as a legitimate peaceful purpose.

- *Even with access to reliable air links, it is still essential that Antarctic projects be planned 18 months to 3 years in advance. The way to position substantial supplies and cargo, large equipment, or construction material necessary during a given summer season is to deliver it by ship during the previous summer. This means the material must be procured in time to be positioned for the annual cargo ship loading in November, 1 year earlier than the start of the project in Antarctica. This then describes the flip-side of the beneficial availability of an intercontinential air link: there is a tendency to abuse the air link because it is easy and appealing for the science or support project organizer to have cargo moved only by air. The penalty in dollars can be great—since the cost of moving a pound of cargo from the United States to McMurdo by ship is less than 10 cents, and by air is about $10.*

- *For the Antarctic logistician there are important changes underway. Antarctic telecommunications have always been in a dismal state. Long-range high-frequency radio propagation in the high magnetic latitudes and the auroral zone around the pole has proven unreliable to the point of*

The Amundsen-Scott South Pole research facility, most of which is under the snow. (Photo courtesy of NSF)

> *frequent and extended blackout. But no more. Satellite communications have finally arrived. Virtually all the national programs use the International Marine Satellite (INMARSAT) for stations and ships in the Antarctic. In a similar way, we are at the threshold of dramatic increases in the use of remote sensing. Space-based instrumentation and data relay for automated observations of Antarctic phenomena may soon get a dramatic boost as dedicated satellites are put in orbits with optimum coverage—either as instrumentation platforms or as data links for the south polar regions.*

Some Last Words

The very appearance of this issue of *Oceanus* illustrates the increasing level of interest in Antarctica. The expansion of human activity in recent years will undoubtedly continue, yet the exploitation of mineral resources will not necessarily occur as a result. Commercial activity—tourism—is already a rapidly growing reality. Scientific research also will continue to grow in sophistication, interdisciplinary complexity, and international cooperation.

In the realm of logistics, profound changes are taking place: computerized data processing and satellite communications, for example, have become vital not only to supply and support functions, but also to science. The realm of commercial and general aviation is being extended south of the 60th parallel. However, to complement airlift growth to and within Antarctica, there also must be an increase in sealift—to position the fuel, if for no other reason. Tomorrow's scientists, tourists, and essential support people may very well reach Antarctica and move about by air, but supplies and equipment, construction materials, waste, and above all, fuel, will be positioned by ship.

The survival beyond 1991, the continued effectiveness of the Antarctic Treaty System, and the orderly evolution in logistics and environmental protection, may well lead to a bright new day in Antarctic science. Because of the significant role of the great polar ice-covered continent to the world environment in an era of global change, this may prove vitally important to all of us.

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Selected References

Scientific Committee on Antarctic Research International Council of Scientific Unions. 1985. *Man's impact on the Antarctic Environment.* Cambridge, England: SCAR, Scott Polar Research Institute.

Spletstoesser, J. 1985. Remote camps for U.S. field projects in Antarctica. *Antarctic Journal of the United States,* 20(2): 1–7.

National Science Foundation. 1979. *Antarctic Conservation Act of 1978.* Washington, D.C.: National Science Foundation.

The Soviet

Antarctic Program

by Lawson W. Brigham

The Soviet Union's programs in Antarctica are highly orchestrated, long-term in nature, and of significant scientific merit. The Soviets have been an active and influential research participant in Antarctica since the International Geophysical Year (IGY) in 1957–58. Soviet IGY observations in meteorology, glaciology, and coastal oceanography were particularly important to the development of future research objectives and methodologies of many projects. Today, approximately 15 percent of the Antarctic scientific papers contributed by treaty nations come from Soviet researchers. The Soviet Union also has a significant voice in the Scientific Committee for Antarctic Research (SCAR)—an active player in the decisions on international exchanges, the pooling of data, and the coordination of various scientific programs.

Role of the Scientific Research Institute

The Soviet Antarctic program is coordinated by the Arctic and Antarctic Scientific Research Institute in Leningrad. The institute was formed on 4 March 1920. It held several different names under various government bodies during its first two decades of existence. Nearly 300 expeditions were sent to the Arctic by the institute during 1920–1945. The institute has been associated closely with all recent Soviet Arctic expeditions (including many pioneering drift stations in the central Arctic), and the development of viable marine transportation in the Soviet north.

Above, the Soviet station Leningradskaya. (Photo courtesy Rauma-Repola, Finland)

Within the Soviet system, the institute is considered a central research institute for organizing and directing all disciplines of polar research. Although other institutions of the Soviet Academy of Sciences, ministries, and universities (for example, the Ministry of Geology, the Institute of Oceanography of the Academy of Sciences, the Ministry of Fisheries, the Institute of Geography of the Academy of Sciences, and Moscow and Leningrad Universities) conduct research in the polar regions, the Arctic and Antarctic Scientific Research Institute enjoys a pre-eminent position. Most leading Soviet polar scientists deal with the institute because of its extensive polar archives, experienced staff (several thousand researchers), and important contacts with government bodies responsible for air and sea logistics.

Central organization of the Soviet Antarctic program occurred in 1958, when the then-named Arctic Scientific Research Institute was given control of coordinating both the science and logistics of the program. Although influenced by the Academy of Sciences and dependent on other government departments, the institute has smoothly coordinated the annual Soviet Antarctic Expedition for the last 30 years. The natural integration of science and logistics for both the Arctic and Antarctic has made the institute a highly effective organization.

Recent Research

One of the most intriguing Soviet Antarctic projects has been the deep drilling program at Vostok Station. During 1972–83, a thermoelectric drill was used to reach a depth of 2,083 meters in glacial ice that is 3,700 meters thick. Ice cores taken from depths of less than a kilometer have been determined to be 50,000 years old. The deepest ice core taken from Vostok in 1986–87 had an age of approximately 150,000 years. Analyses of the variations in oxygen isotopes, dust, and carbon dioxide have yielded important information about past climates on the continent.

Geologists and glaciologists with the Vostok drilling program also are attempting to reach several large lakes that are believed to lie beneath the ice cap. Radar surveys have indicated the presence of these "pockets." It is possible these areas at the bottom of the Antarctic ice sheet are at the pressure melting point.

The Vostok program also has a microbiological component. Soviet scientists at the Institute of Microbiology have found simple life forms in the Vostok ice cores from 200 meters that are approximately 8,000 years old. Several species of the microorganisms have been revived after their long dormant period in the Antarctic ice sheet!

Since 1975, the Soviet Antarctic program has devoted considerable research time and logistics efforts to studies of the Weddell Basin and Weddell Sea region. One of the principal objectives is to establish the geological formations of the mountain systems that fringe the Weddell Sea—the Shackleton Range, the Pensacola Mountains, and the Ellsworth Mountains. Keen interest in such a remote region of the globe is understandable—there may be similarities in the geological structures of this area to southern Africa, which is a leading region for minerals production (see also article on page 32). Intensive geophysical surveys of the Weddell Sea by the Soviet Union and other nations are directly related to understanding an offshore region that holds the promise of oil and gas resources.

Seasonal Soviet stations have been established on the Filchner Ice Shelf (Druzhnaya Station), and in other locations around the basin. These have been temporary support bases for geological, geophysical, geodetic, and topographic work along the coast. Geophysical surveys have covered more than 200,000 square kilometers of the Weddell Sea and its surrounding ice shelves. Seismic probes and coring into the sedimentary deposits of the seabed beneath the ice cover have been extensive. Systematic aerogravity and aeromagnetic surveys have helped to integrate information on both offshore and inland areas. Soviet geologists have collected extensive rock and mineral samples from the surrounding mountains. One of their significant findings was an accumulation of fossil trilobites, primitive animals (related to spiders and insects) that lived millions of years ago.

Glaciological traverses across the Antarctic ice cap by tractor train have been a common element in each of the Soviet Antarctic Expeditions. In the 1950s, Soviet tractor-sled expeditions conducted trips into the heart of East Antarctica, primarily to establish remote stations, such as Vostok. However, in recent years, many have been continued for scientific purposes. In the mid-1970s, as part of the International Antarctic Glaciological Project (a decade-long investigation of the East Antarctic ice sheet), Soviet research traverses collected gravimetric and magnetic observations, and drilled hundreds of bore holes for glaciological measurements. In cooperation with Australian glaciologists, geoceivers were positioned to obtain precise position and elevation measurements. During several field seasons of Soviet traverses, remeasurements of these positions yielded valuable flow velocities of the East Antarctic ice sheet.

Soviet Oceanographic Research

Ships and oceanographic research have played prominent roles since the inception of the Soviet Antarctic program. A. F. Treshnikov, a noted Soviet polar scientist, has outlined the basic objectives of these early efforts as:

- *study of the thermal and dynamic regime of the south polar waters, and water/heat exchange with the bordering oceans;*
- *study of the circulation of surface and deep waters;*
- *study of the hydrological regime of Antarctic shelf seas; and*
- *study of the ice regime, features of iceberg distribution, and the physical properties of Antarctic sea ice.*

Although almost entirely descriptive in nature, the

Table 1. Permanent Soviet Antarctic stations.[1] (See also map on page 15)

Name	Location[2]	National Claim or Sector[3]	Date Established	Number of Winter Personnel[4]	Primary Research and Observations
Mirnyy	66°33′S, 93°01′E Coastal Queen Mary Coast	Australia	13 February 1956	61	Meteorology, actinometry[5], seismology, cosmic ray studies, auroral studies, geomagnetism, ionospheric studies, radio wave propagation, medicine, physical geography, glaciology (past).
Vostok	78°27′S, 106°51′E Inland Polar Plateau near the South Geomagnetic Pole	Australia	16 December 1957	26	Deep drilling of the continental ice, microbiological studies, meteorology, actinometry, geomagnetism, cosmic ray studies, glaciology, medicine, auroral studies, radio wave propagation, ionospheric physics.
Novolazarevskaya	70°46′S, 11°50′E Coastal Queen Maud Land	Norway	18 January 1961	34	Meteorology, actinometry, geomagnetism, seismology (deep seismic soundings), auroral studies, physical geography, glaciology, medicine, sea-level studies.
Molodezhnaya	67°40′S, 45°50′E Coastal Enderby Land	Australia	23 February 1962	117	Main Soviet Antarctic base (Soviet Antarctic Meteorological Center), tracking of geodetic satellites, rocket sounding of the atmosphere, meteorology, actinometry, geomagnetism, auroral studies, glaciology, medicine, radio wave propagation, artificial satellite photography, ice shelf drilling, biology, geology.
Bellingshausen	62°12′S, 58°58′W King George Island South Shetland Islands	UK/Argentina/ Chile (Overlapping Claims)	22 February 1968	29	Meteorology, glaciology, hydrology, actinometry, geomagnetism, medicine, ice-cover and iceberg studies, physical geography.
Leningradskaya	69°30′S, 159°23′E Coastal Oates Coast	Australia	27 January 1970	12	Meteorology, geology, geomorphology, gravity, geomagnetism, astrogeology.
Russkaya	74°46′S, 136°51′W Coastal Hobbs Coast Marie Byrd Land	Unclaimed	10 March 1980	9	Meteorology, glaciology, ionospheric studies, atmospheric pollution (snow analyses).

Notes:
[1] Year-round stations only; the Soviet Union operates seasonal stations occasionally for special projects.
[2] Coordinates from *Polar Record*, 23(147): p. 751 (1987).
[3] Claims held in abeyance by the Antarctic Treaty; Molodezhnaya located near the sector line between Norwegian and Australian claims in Queen Maud Land; Leningradskaya located near the sector line between New Zealand and Australian claims on the Oates Coast.
[4] 1980 data from *Antarctic Journal of the United States*, 16(1): p. 5 (1981).
[5] Measuring the direct heating power of the Sun's rays.

early Soviet Antarctic oceanographic effort produced valuable results. Meridional (running in a north-south direction) oceanographic sections were taken from the coast of Antarctica to the subtropic convergence zone (40 degrees South). Annual observations were taken along standard sections from Antarctica to Australia, and Antarctica to Africa; the sections revealed annual shifts in the position of the Antarctic Convergence Zone.

During this period, the general circulation patterns and basic water masses of the Southern Ocean were catalogued in an *Atlas of the Antarctic*. The first estimates of water through Drake Passage also were made, and detailed sea-ice maps were prepared for the entire continent. Hydrographic stations were taken in shelf areas, such as Prydz Bay off the Amery Ice Shelf, that had never before been investigated.

During 1956–70, the research vessel *Ob′* conducted extensive operations in the Southern Ocean; more than 1,000 oceanographic casts and 264,000 nautical miles of echo-sounding profiles were accomplished. Of primary importance were the comprehensive biological investigations conducted by the *Ob′*, studies primarily concerned with oceanic plankton, sea-floor invertebrates, and fish populations. The early expeditions allowed Soviet investigators an opportunity to compare plankton from the Southern Ocean with collections taken from the Arctic Ocean. These initial Soviet ecological investigations paved the way for further scientific and commercial studies regarding utilization of fish and krill resources in Antarctic waters.

Beginning in the early 1970s, the Soviet Union averaged three to four research vessels in the Southern Ocean during austral summer. The Soviets implemented POLEX-South (South Polar Experiment), a long-term, large-scale study of air/sea interaction around the Antarctic continent. Extensive investigations were conducted on the structure and variability of the Antarctic Circumpolar Current (ACC). For the first time, instrumentation was used to measure mesoscale and seasonal oscillations of the

The Akademik Fedorov, *new Soviet research flagship, in Antarctica in March 1988. (Photo courtesy of Rauma-Repola)*

current. At depths of 3,000 meters, near the ocean floor, current velocities of 50 to 70 centimeters a second were recorded.

During the 1976–77 expedition, the *Professor Zubov*, while investigating the East Wind Drift along stations between Australia and Antarctica, identified a countercurrent beneath the Antarctic Circumpolar Current (ACC). The countercurrent ranged in thickness between 1,500 and 2,500 meters, and had a measured velocity of up to a nautical mile an hour. Soviet-American collaboration on studies of the ACC during these years established that this current is stable, broadly developed, and actually a "multi-jet" system of currents (see page 53). Its volume transport was found to be several times larger than any other known current system. Clearly, the circumpolar current was confirmed as the dominant circulation system in the Southern Ocean.

An unusual joint oceanographic expedition in the Southern Ocean was carried out aboard the Soviet Antarctic flagship *Mikhail Somov* during October and November 1981. The U.S.-Soviet Weddell Polynya Expedition was planned to investigate a polynya (an area of open water in sea ice, and a word coined by the Russians) that had been observed on satellite imagery within the Weddell Sea since 1973. The polynya, originally located near the Greenwich Meridian and 65 degrees South, appeared and disappeared in subsequent winters, growing at one time to nearly 300,000 square kilometers. Such a feature is believed to have important climatic and oceanographic implications (see also page 39). Upwelling warmer waters lose heat through polynyas, thereby causing cooling of the deeper waters below.

For the first time, oceanographic data also were collected in late winter within the Weddell Sea. While there was no clear indication of the polynya in 1981, observations (sea water, ice, and air) were taken from the ice edge to a point 300 nautical miles within the Weddell Sea ice cover. The data yielded significant clues regarding the end of the seasonal growth period of sea ice. The cumulative effects of sea-ice formation cause a seasonal maximum in sea-water density (just below the ice cover), which ultimately influences the formation of deeper waters.

Oceanographic investigations under POLEX-South have continued in recent years. Work in the Weddell Sea and near Maud Rise has concentrated on the mechanics of formation of intermediate and bottom waters, and their role in global ocean circulation. During the 1985–86 season, two research vessels investigated the western Pacific sector of the Antarctic for the first time. Comprehensive studies of the shelf waters (formed in the Weddell Sea, Ross Sea, Davis Sea, Prydz Bay, and other coastal areas), and the mechanisms by which they mix with warmer, deep waters will be continued by Soviet oceanographers in the future.

Future Trends

The future of the Soviet Antarctic program appears bright. Improved air logistics, using compacted snow runways, will allow routine flights of heavy aircraft to the Antarctic directly from the Soviet Union. One objective is to airlift all Antarctic personnel to their stations by the end of the current 5-year plan in 1990. Thus, winter personnel changes will be more efficient and timely, and more cargo may be airlifted, reducing the number of support ships. The Soviets will have new mobility, flexibility, and reach with which to support field research around the continent.

In late 1987, the Soviet Union enhanced its maritime presence around Antarctica with the arrival of a new flagship, the *Akademik Fedorov*. Built by the Finnish shipbuilder Rauma-Repola OY, the 140-meter vessel is capable of resupplying Soviet stations and transporting 160 personnel. The ship also is a floating research station equipped with 10 laboratories designed for a wide spectrum of atmospheric, marine, and polar sciences. A 20,000 horsepower diesel-electric power plant, more than twice the power of the *Mikhail Somov*, will allow the ship to proceed continuously in 1-meter level ice.

This improved ice-breaking capability will allow marine scientific research to be conducted in continental shelf areas yet to be fully explored, and will improve the reliability of coastal resupply efforts. The *Akademik Fedorov* also is fitted with modern polar navigation equipment, research computers, bow and stern thrusters for positioning, extensive cargo handling gear, and associated equipment for flight control, maintenance, and operation of Soviet MI-8 and KA-32 helicopters.

The Soviet Antarctic program thus can support a greater number of field stations on ice shelves and at remote land sites some distances from the major Soviet bases. On 19 January 1987, a new seasonal station, Druzhnaya 3, was established near the Quar Ice Shelf on the coast of Queen Maud Land. This would appear to be an extension of past, intensive geophysical survey efforts conducted in the vicinity of the Weddell Basin.

Three Soviet summer stations operated last year near Lambert Glacier and Amery Ice Shelf in East Antarctica. Soyuz Station reopened on Beaver Lake in the Prince Charles Mountains, and two new summer stations were established—Progress on the southeast coast of Prydz Bay, and Druzhnaya 4 on

Significant Events in the Soviet Antarctic Program

- **13 July 1955**
  First Soviet Antarctic Expedition (SAE) organized by the U.S.S.R. Academy of Sciences to coordinate Soviet work during the International Geophysical Year.
- **13 February 1956**
  First Soviet Antarctic station, Mirnyy Geophysical Observatory, established on the Davis Sea.
- **16 December 1957**
  Soviet flag hoisted at the inland station Vostok at the South Geomagnetic Pole, 1,410 kilometers from Mirnyy Station.
- **1958**
  Arctic Scientific Research Institute in Leningrad entrusted with the organization and coordination of all Soviet research in Antarctica; henceforth called the Arctic and Antarctic Scientific Research Institute.
- **2 November 1960**
  Soviet Union ratifies the Antarctic Treaty.
- **December 1961**
  First long-distance flight of Soviet aircraft from Moscow to Antarctica.
- **January–March 1964**
  Seventy-eight-day, 3,323-kilometer scientific tractor-sled traverse (Vostok Station to the Pole of Inaccessibility to a turning point at 78° 03′S, 19° 59′E to Molodezhnaya Station); observations included seismic, gravimetric, glaciological, meteorological, geomagnetic, and actinometric.
- **1966–69**
  Soviet Union publishes first large-scale, comprehensive Antarctic Atlas *(2 volumes), incorporating data obtained by scientists from various nations, particularly the USSR.*
- **1968**
  Arctic and Antarctic Scientific Research Institute extends its oceanographic investigations to the Southern Ocean after receiving several research vessels, including Professor Vize, Professor Zubov, *and* Okianograf.
- **1971**
  Functions of the Antarctic meteorological center transferred from Mirnyy Station to Molodezhnaya Station, which becomes the main Soviet Antarctic base.
- **1974–75**
  Drilling begins at Vostok Station during the 20th SAE for microorganisms in the Antarctic ice sheet, using a mobile drilling rig that preserves sterile conditions.
- **1976–82**
  Extensive Soviet geophysical studies in the Weddell Sea basin coordinated from a seasonal base (Druzhnaya) on the Filchner Ice Shelf.
- **February 1980**
  First IL-18 aircraft from the Soviet Union arrives at a new permanent, compressed snow runway (2,645 meter length) near Molodezhnaya Station; trial route flown by way of Moscow, Odessa, Aden (Yemen) and Maputo (Mozambique).
- **1981**
  Joint U.S.S.R./U.S. oceanographic investigations in the Weddell Sea aboard the Soviet Antarctic ship Mikhail Somov.
- **February 1986**
  First landing of wide-body cargo aircraft (IL-76) from the Soviet Union to the Molodezhnaya Station snow runway.
- **1987**
  New Soviet Antarctic research and supply icebreaker Akademik Fedorov *deploys on first cruise to the Southern Ocean.*

Sources: **Antarctic, Polar Geography and Geology, Pravda, Problemy Arktiki i Antarktiki, Soviet Antarctic Expedition Information Bulletin, *and* Vodnyy Transport.**

The Mikhail Somov, *a Soviet icebreaker, during the 1981 Weddell Polynya Expedition. (Photo courtesy National Science Foundation)*

the Amery Ice Shelf. Scientific programs at these locations emphasize the study of metallic minerals and extend geophysical investigations, including multi-channel seismic surveys, conducted throughout Prydz Bay during the last decade. The ability to support these outposts by air and sea reflects an improving and confident logistical system of the Soviet Antarctic program.

One of the hallmarks of Soviet Antarctic research has been an extensive meteorological program. Molodezhnaya Station, the meteorological center, continues to be upgraded with modern equipment, including the capability of receiving enhanced satellite imagery, such as that of Cosmos-1,500 with its side-scan radar. The ring of Soviet Antarctic stations around the continent also provides retrieval of an important set of surface and upper atmospheric observations. These data are analyzed at Molodezhnaya, where weather services are provided to all Soviet Antarctic operations. The 30-year record of weather data is critical to studying climatic variations, and central to Soviet research on applying numerical models to long-term forecasting. Future global atmospheric research programs will likely make extensive use of this important Antarctic data base.

Soviet Antarctic activities will continue to apply lessons learned from their vast knowledge base regarding the Arctic. In a symbiotic way, the Soviet Antarctic research program will return the favor by providing data that are applicable to the extreme climates and difficult living environments of the Soviet north. Some future Antarctic research, particularly medical studies, will have utility within the Soviet space program.

The presence of the Soviet Union in Antarctica is secure. An improved and efficient logistics system, effective maritime presence, a highly coordinated research program, and the location of stations rimming the continent place the Soviets in a position of strength as they look forward to the increasingly complex polar politics that seem ordained for the 1990s.

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The views expressed in this article are solely those of the author and do not necessarily reflect the position of the the U.S. Coast Guard or the U.S. Government.

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Coldest Place on Earth

The highest (3,488 meters above sea level) and most remote manned station in Antarctica was established by the Second Soviet Antarctic Expedition in 1957. Known as Vostok Station, it is located on the Polar Plateau near the South Geomagnetic Pole in East Antarctica. Here the polar ice thickness is 3,700 meters.

Except for a year of mothballing (21 January 1962–25 January 1963), this inland station has remained manned throughout the winters by approximately 25 people, including American exchange scientists. Each year Vostok is supplied by air and by a tractor-sledge traverse from the Soviet coastal station Mirnyy, 1,500 kilometers away.

Vostok Station is perhaps best known for a record low temperature of −89.6 degrees Celsius (−128.6 degrees Fahrenheit) recorded 21 July 1983. The annual mean air temperature at Vostok is −55.6 degrees Celsius compared to a mean of −50 degrees Celsius at the U.S. Amundsen-Scott South Pole Station. This Soviet scientific outpost has appropriately earned the dubious distinction of "coldest place on Earth"—the coldest inhabited location on the planet!

—LWB

concerns

Bound For 60 South— Taxes, Tips, and Transfers Included:

The Growth of Antarctic Tourism

by Paul Dudley Hart

Recent growth of tourism in Antarctica poses a thorny problem for treaty nations in the not-too-distant future. On the one hand, continued growth will pose a threat to the pristine nature of the continent and the science conducted there, while, on the other, treaty regulations recognize the right of tourists to visit the area. It has been estimated that 3,000 tourists visited the region in the 1987/88 season—either by boat or air. It is time to prepare, if not implement, measures to monitor, and, where necessary, regulate tourism.

Mention of Antarctica often elicits a response from people that displays profound ignorance—"Now, is that the North or South Pole?" On rare occasions, a response will display an equally profound fascination, sometimes purely romantic, or else stemming from a specific personal interest, such as the history of the continent's exploration, or its flora or fauna. Antarctic tourism, a concept as alien as space tourism little more than two decades ago, was originally created to profit from those people who wanted to experience the source of their fascination first hand. Certain regions of Antarctica have become regular, though not yet commonplace, tourist destinations.

The majority of Antarctic tourism is concentrated in the Antarctic Peninsula, the closest to regular transportation networks in South America. Dubbed the "Antarctic Riviera," the peninsula has the largest concentration of national research stations, partly as a geopolitical consequence of overlapping national boundary claims, and partly because of the same logistical considerations—cost and travel time—that make it the primary destination of tourists.

Visitors, Problems, and Rights

Despite some oscillation, the general trend of increasing Antarctic tourism is a subject of concern among signatory nations to the Antarctic Treaty. Although the numbers of tourists in absolute terms seem insignificant when compared to the numbers of passengers regularly disgorged from ships and planes at more commonplace destinations—such as islands in the Caribbean—some fundamental differences separate the Antarctic from conventional tourist destinations. In most countries, conscious decisions have been made to trade different degrees of environmental damage for improved economic conditions. In most locations, there also is some organization with the task of protecting the local environment. Although the results of such measures range from successful environmental conservation linked with significant economic benefit, to abject failure on both counts, there is some community responsibility and consequence. In Antarctica, there is no local populace to reap the economic benefits of tourism, nor is there an effective means beyond the boundaries of national research stations to properly monitor its impact.

Proponents of unregulated tourism argue that the tourists who now visit Antarctica annually have no significant detrimental impact on the area, which covers almost 10 percent of the Earth's land surface. This is partially true. Antarctica is being more profoundly affected by changes in the global atmosphere caused by fossil-fuel burning and fluorocarbon emissions than by tourism. But in specific places, tourism does pose a threat. First, by its focus on one particular area, the Antarctic

The M/V Society Explorer, *a tourist cruise ship, in Antarctic pack ice. (Photos by Paul Dudley Hart)*

Peninsula, and second, by further concentration on the relatively few locations that afford safe landing sites—both snow and ice free in the austral summer—for seaborne and airborne tourists. Seaborne landing sites also tend to be the principal locations of plant and animal life, thus adding to their attraction.

Man is the most recent and least adapted addition to life in Antarctica. Through whaling and sealing, he already has been the most destructive. In present times, inadequately briefed or supervised, a very small number of visitors can wreak havoc on a seal colony or seabird rookery, and the best supervised visits to any one particularly favored site, if too frequent, can be destructive.

Although the Antarctic ecosystem is extraordinarily robust, it is so only within the parameters of its own evolution. Expanding on an example drawn from I. Everson in *Antarctic Science*, edited by D.W.H. Walton, an average human foot exerts 2 ½ pounds per square inch, a greater pressure than an Antarctic plant, such as moss, has had to withstand in its natural evolution from indigenous animals. Its broken surface, once exposed to wind, will erode far faster than its slow regenerative capacity. Thus, tour operators must assure that their passengers consistently adhere to well-defined procedures that safeguard the Antarctic ecosystem, and be fully cognizant of activities that disrupt or disturb life in the region.

Antarctica is the natural equivalent of a "clean laboratory." By its pristine nature, it serves as a benchmark against which other ecosystems around the world can be compared. Long-term experiments regularly take samples from the Antarctic continent, ocean, and atmosphere to define the rate at which natural and man-made elements are assimilated into the Antarctic ecosystem, thus providing information on their abundance, environmental fate, and circulation pathways and rates.

Ocean circulation measurements (see pages 39 and 53), taken in Antarctica are vital to understanding the dynamics and interrelation of global processes. It is essential that tourism activities do not disrupt research by excessive demands for research station visits by regular tour operators, incursions into areas of special scientific interest, or causing the diversion of treaty nation research assets to assist or rescue tourist expeditions.

Despite the complex management and monitoring problems imposed collectively, but not equally, on treaty nations by tourism and occasional, but significant, disruptions to national

research programs caused by rescue missions to private expeditions, the basic right of the tourist to visit Antarctica is not questioned by treaty nations. Tourism is a legitimate, peaceful use of the Antarctic. Freedom of access is granted in the Antarctic Treaty (see page 11).

Seaborne Tourism

Seaborne tourism generally falls into three categories—expedition/educational cruising, traditional "fun-in-the-sun" cruising, and passenger-carrying government shipping.

Expedition/educational cruising is the most popular form of Antarctic tourism. While tourists have visited Antarctica each year since 1958, the concept of "expedition tourism" was pioneered both in Antarctica and elsewhere by Eric Lars Lindblad. Lindblad perceived that a certain section of the traveling public sought challenge and education as the principal ingredient of their vacations—rather than rest and relaxation. Acting on this perception, he organized the first expedition cruises to Antarctica in 1966. With the collaboration of the Argentine government, tourists visited the Antarctic Peninsula on the *ARA Bahia Aguirre*, an Argentine Naval transport adapted to accommodate a limited number of passengers. Lindblad utilized this ship and other government vessels until 1969.

The first privately owned passenger ship specifically built for Antarctic cruising—the *M/V Lindblad Explorer*, a 2,500-ton, 100-passenger, ice-strengthened vessel—was built in Finland and launched in 1969. With this ship, Lindblad, despite grounding incidents in 1972 and 1980, developed a successful model for Antarctic passenger cruising, establishing the standard against which other similar operations are compared. In 1984, the *Lindblad Explorer* was acquired by Discoverer Reederei, a shipping company based in Bremen, Germany. In 1978, this company had introduced another slightly larger Antarctic cruise ship, the *M/V World Discoverer*, a 3,200-ton, 140-passenger ice-strengthened vessel. The *World Discoverer*, and the *Lindblad Explorer*, renamed *Society Explorer* since its acquisition by Discoverer Reederei, have been under exclusive charter to Society Expeditions, Inc., an "expedition tour" company based in Seattle, Washington, under the same ownership as Discoverer Reederei, that books the passengers and organizes the content and itinerary of the cruises. Lindblad Tours re-entered the Antarctic "expedition cruise" arena in the 1987/88 season by chartering the *M/V Illiria*, a 140-passenger Greek ship of comparable size to the *World Discoverer*, though not ice-strengthened, for her first Antarctic season.

The philosophy of the cruise model initiated by Lindblad and further refined by both his organization and Society Expeditions is one of "leave only footprints." To their great credit, this is largely the case.

The most successful tour operator, Society Expeditions, schedules cruises of 15 or 25 days duration. Usually their cruises sail from the port of Punta Arenas on the Strait of Magellan, or Puerto Williams on the Beagle Channel, both in Chile. All cruises include the Antarctic Peninsula, with some also stopping at the Falkland and South Orkney Islands, South Georgia, or the Chile Canals to as far north as Puerto Montt. "Circumnavigation" cruises to New Zealand via McMurdo Sound in the Ross Sea and the Antarctic Peninsula from South America also have been undertaken, although less regularly.

A lecture staff of individuals experienced in specific aspects of Antarctica, such as ornithology, history, zoology, botany, geology, or political science, sails with the ship. The task of these lecturers is to educate passengers through lectures and conversation, and to act as guides ashore. Sometimes three or four landings are made by outboard powered inflatable boats in a single day. Some landings are made at research stations, others at uninhabited areas. At locations where landing the full complement of passengers is disruptive either to workings of a particular research station, or to animal communities at an uninhabited site, passengers are disembarked in shifts of small groups.

Author's Tour Experience

During February of 1988, the author embarked for the first time on a tourist cruise to the Antarctic Peninsula on the *M/V Society Explorer*. Aboard for three weeks, he observed excellent standards of seamanship and safety, quite comparable to those viewed aboard U.S. government vessels operating in Antarctica and superior to those viewed aboard some government vessels of other nations. At no time during the cruise was any trash jettisoned from the ship or discarded ashore. All trash was compacted and unloaded at South American ports. Lectures generally were very good, presenting information about Antarctica that was both understandable and accurate. Pre-landing briefings given by the "expedition leader" informed passengers of the conditions that they were to encounter, and particular safeguards necessary at each site. The passengers also were told of any site-specific environmental preservation measures.

Ashore, passengers were shepherded by lecturers who firmly, but politely, corrected any passenger who, usually through inattention, did anything to endanger their own safety or the local environment. Passengers usually cooperated wholeheartedly.

The only criticism the author would offer is that too much time was spent on visiting national research stations. A visit to one or two stations is warranted to allow passengers to view an important aspect of contemporary Antarctica and to speak to people actually conducting research. More visits tend to become repetitive for passengers, and disruptive to research at the stations. As a consequence, some nations, including the United States and Britain, have restricted the number of tour visits permitted at their stations. The United States has further restricted the visits to the exterior areas of its bases. From the author's observations, passengers appear more content not being able to visit a station at all, rather than being able to visit,

Tourists coming ashore from the M/V Society Explorer *in Antarctica.*

but kept at arm's length while at the station. It is the author's personal view that fewer visits, with a more wholehearted welcome, including entry into some representative areas of the station, would be a better policy.

Each nation has two principal reasons for maintaining its stations in Antarctica—geopolitics and science. It can be argued that the degree of welcome afforded to tourists at each station is indicative of the relative importance a nation places on each reason.

The "leave only footprints" philosophy of the Society Expeditions/Lindblad cruise model appears to be taken very seriously. Through professionalism, and adherence to a degree of environmental awareness rare in a for-profit venture, these expedition cruises have achieved the best of all solutions in Antarctic tourism—self-policing. As a global solution, unfortunately, it is the least reliable.

'Fun-in-the-Sun' Cruising

Conventional "fun-in-the-sun" cruising has not fared nearly as well in Antarctica. Sporadic attempts to introduce it have failed because of problems that have, as yet, no apparent solution. Passengers are drawn to such cruises for social and entertainment reasons.

Relaxation on deck, frequent port stops for shopping, wining and dining, and nightlife entertainment are the principal draw for most traditional cruise ship passengers. Being on deck in the Antarctic means being dressed from head to foot, and even then often experiencing discomfort. There are no port stops, and shopping is limited to emblematic patches at the few stations capable of accommodating large ships and their passengers. Wining and dining ashore is nonexistent, and shipboard nightlife is frequently disrupted by the ship's reaction to the gales and sea conditions prevalent in the area—an obvious marketing problem.

The *Society Explorer* and *World Discoverer*, though comfortable, are small ships designed for the maneuverability and the relatively shallow draft necessary to safely navigate in waters restricted by ice and shoals. These same qualities, shared, other than ice-strengthening, by *Illiria*, grant such ships access to landing sites that larger passenger ships cannot safely approach.

Landings present other safety, logistical, and supervisory problems. Conventional cruise ships carry anywhere from 500 to 1,000 passengers at a time. Such numbers, even at an accessible site, cannot be put ashore at one time at any location with plant and animal life. Cycling passengers ashore in similar numbers to the "expedition" cruise ships is too time consuming. Very few stations are willing to accept such numbers either, unless a particular nation with adequate base facilities is involved with the operation and has some specific motive for having the tourists there. During the 1987/88 season, plans were made to utilize the *Mediterranean Sky*, a large cruise vessel, to transport tourists to the Peninsula 600 at a time. To the relief of many, this project either has been postponed or abandoned, apparently because of a lack of bookings.

Since 1958, the Argentine government, principally through its Sport and Tourism Department, has organized "traditional" cruises, first with relatively small, and then with larger numbers of passengers utilizing ships such as *M/S Les Eclaireurs, Lapataia, Libertad, Rio Tunuyan, Regina Prima, ARA Bahia Buen Sucesso*, and *ARA Bahia Paraiso* (the last two again being naval auxiliary transports). Chilean government vessels, since 1959, also have been transporting tourists to

Antarctica, though in smaller numbers, aboard the *Navarino, Yápeyu,* and *Aguiles*. In 1973/74 and 1974/75, Ybarra Lines of Spain transported passengers to the Antarctic aboard the *M/S Cabo San Roque*, and *Cabo San Vincente*, as did Costa Lines with the *Enrico C* in 1976/77. But each of these activities was discontinued. In recent years, both Argentina and Chile have continued to convey tourists aboard their Antarctic vessels. On these government ships, landings are made principally at the station or stations of the nation in question, only on some occasions at those of other nations. As official treaty nation ships, they have the right to call at the stations of other nations, but they do not necessarily have the right to land uninvited tourists.

In summary, tourism aboard official treaty nations vessels is the responsibility of the nation conveying them. Large, conventional cruise ship tourism to the Antarctic presents a major safety, environmental, and station disruption threat. To date, however, the use of large cruise ships does not appear to be economically or practically viable.

Expedition cruise ships, on the other hand, thus far appear to be doing a good job of policing themselves. But, this may not be sustainable. The expedition cruise concept's success and the high degree of passenger satisfaction to date is likely to cause more rapid growth and bring new players, such as the *Illiria* into the arena. It is unlikely that any new players will be as responsible as Lindblad and Society Expeditions have been. Consequently, this issue could be forced out of the discussion stage among the treaty nations and into some form of, hopefully enlightened, direct monitoring and regulation.

Airborne Tourism

In 1977, frequent air tourism was introduced when a chartered aircraft belonging to Qantas, the Australian airline, overflew Antarctica in the Ross Sea area for sightseeing purposes. This means of tourism, which proved to be popular and economically viable, was continued by irregular flights by Qantas and Air New Zealand, primarily over the Ross Sea area, carrying as many as 300 passengers on each flight.

In November 1979, this form of tourism ceased after an Air New Zealand flight crashed into the slope of Mount Erebus, close to the U.S. McMurdo and New Zealand Scott stations on Ross Island. All 257 persons aboard the plane were killed—the single largest loss of human life in Antarctica. The toll exceeded this century's deaths in Antarctica from all other expeditions.

Airborne tourism since has taken place primarily in the western sector, the Antarctic Peninsula, for the same logistical reasons as seaborne tourism. Flights in recent years using Twin-Otter or similar aircraft have flown from airfields in Chile to the Peninsula area, principally the Chileno Teniente Marsh and Presidente Frei Stations on King George Island in the South Shetland group. Teniente Marsh Station now has a 100-bed hotel and bank for visitors. Spending a few days at the station, visitors can view a variety of wildlife sites on the island.

On January 12 of this year, tourism reached the South Pole itself. Tourists, transported from Chile via peninsular and continental airfields, landed at the U.S. Amundsen-Scott South Pole Station aboard Twin-Otter ski-equipped aircraft. The tour, organized by Adventure Network, a Canadian organization, was comprised of eight passengers, mostly American, who had paid up to $35,000 each, and two crew. They spent 2 hours and 35 minutes at the station. During this period, they entered the station, were given a cup of coffee, allowed to buy two souvenirs each, and permitted to walk about outside.

Many of the passengers were relatively elderly. Some had to have oxygen administered to them on the flight (oxygen is normally used in aircraft above a ceiling of 10,000 feet) and, according to *The New York Times* of February 7, 1988, some had difficulty breathing and moving around while at the station, which is at 9,200 feet, but equivalent in oxygen content to an altitude of 11,000 feet. While reactions by station personnel were varied, the visitors were generally viewed as being poorly prepared for the excursion. Four visitors were unable to walk the 100 yards back to the plane and had to be driven in a station vehicle. The station manager also had to explain to the pilots the importance of the aircraft remaining outside the station's Clean Air Research Sector to prevent impact on ongoing atmospheric research. Two other flights have followed, each with 6 passengers and 4 crew.

As indicated by the Air New Zealand disaster, and another fatal crash in January, 1986, at Nelson's Island that killed 8 tourists and 2 crew in a Cessna 404 aircraft, airborne tourism in Antarctica is particularly perilous. The Antarctic has no international air traffic control and virtually no navigational aids. The blizzards, white-outs,* and other phenomena that routinely occur in Antarctica, are not within the experience of most pilots. The United States, for example, selects for Antarctic service fixed- and rotary-wing aircraft pilots from the best available in the military.

Adventurers

There always have been those who seek to test their mettle against harsh and dangerous environments and this desire has most certainly been an important factor in the history of Antarctic exploration. What has changed in the last 20 years is that more people have the money to pursue their desire for adventure.

For many modern adventurers, Antarctica represents the ultimate challenge, whether they be yachtsmen, mountaineers, private pilots, or individuals pursuing some personal quest. Some

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* A surface weather condition in polar regions in which no object casts a shadow, the horizon cannot be seen, and only dark objects are discernable. The phenomenon is caused by a heavy cloud cover over a snow surface, so that light coming through the clouds is essentially equal to the light reflected off the snow.

The author in a penguin suit, celebrating Christmas 1987 in Antarctica.

private "adventure" expeditions have been thoughtfully planned, and courageously, but safely, executed. More have been ill-advised and have placed the lives of expedition members, and sometimes others, in jeopardy.

Whether by plane or sea, private "adventure expeditions" to Antarctica raise the same safety question as commercial tourism, but, usually, with an even higher level of risk. Few, if any, vehicles, boats, or planes, available or affordable to the private consumer, are suitable for use in the Antarctic. Private expeditions also tend to fail to estimate adequately the quantity of supplies necessary. This results in their calling at research stations to request food, medication, spare parts, or other supplies. Since many of these requests could result in some threat to the safety of the expedition if refused, such items are usually granted despite limited availability.

While the responsibility for the safety and execution of private expeditions rests on their organizers, they cannot humanely be ignored by treaty nations in the event of life-threatening emergencies. This assurance is certainly a factor in the planning of such expeditions, and of concern to treaty nations. Private expeditions, especially yachts, do not always seek the advice of treaty nations, nor notify them of their precise intentions. So their whereabouts at any point in time are frequently unknown.

Ignorance of the true conditions that will be faced can lead to an "it won't happen to me" mindset among adventure expedition organizers. This factor is hard to correct, and it is one that leads to expedition organizers who are more willing to risk their lives, through ignorance, than their personal financial assets. A concerted effort through the media, and any other means available, may be of some help. It must be made known that there are not only serious personal risks involved in independent travel to Antarctica, but also that the individuals involved are liable to the extent of their assets for the cost of rescue or assistance.

Summary and Conclusions

Most people who have visited or worked in Antarctica agree that it is one of the most remarkable and profoundly beautiful places on Earth. It is the highest, driest, coldest, sunniest, and most unspoiled continent. It is virtually unpopulated by man and has never had an indigenous human population. Few people returning from Antarctica fail to be untouched by it in some personal way. Many return almost as missionaries, not only for Antarctica's conservation, but also to encourage others to visit and share their enthusiasm.

The investment of time and money involved in traveling to Antarctica as a tourist will continue to limit the growth of tourism. It is certain though, that present levels of Antarctic tourism fall well below the full potential. Thus, appropriate measures must be prepared, if not implemented, in the near future to closely monitor, and, where necessary, regulate tourism.

While this is a single and straightforward statement to make, it will be a very complex task to address effectively. First, while all nations signatory to the Antarctic Treaty are obliged to abide by its terms, national agendas for Antarctica vary, including aspects pertinent to tourism. Furthermore, since some forms of tourism give rise to significantly more concern, and present a greater potential liability in terms of emergency assistance

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Treaty Rules Pertaining to Tourism

The Antarctic Treaty and subsequent approved recommendations have the effect of law for U.S. citizens. The following are articles and recommendations that pertain to tourism.

- **Article VII, paragraph 5** *of the treaty provides the basis for the monitoring of all travel to Antarctica. It requires that all governments inform the governments of other treaty parties of all expeditions to and within Antarctica, on the part of its ships or nationals, and of all expeditions organized in or proceeding from the United States. By extension, U.S. citizens or permanent residents have an obligation to inform the U.S. government of expeditions to Antarctica.*

- *The several relevant recommendations, agreed on at various Antarctic Treaty Consultative Meetings, which bear on the issue of tourism are as follows (roman numerals indicate the meeting number, arabic the recommendation number):*

  III-8: Agreed Measures for the Conservation of Antarctic Fauna and Flora, *establishing Antarctica as a special conservation area and declaring guidelines regarding Antarctic fauna and flora. The recommendation does not address the issue of tourism, per se, but rather proscribes certain activities for all visitors to the Antarctic.*

  IV-27: Effects of Antarctic Tourism, *concerning the need for early notification of tourist visits to Antarctic stations and the possibility that permission might be withheld.*

  VI-7: Effects of Tourists and Non-Government Expeditions to the Antarctic Treaty Area, *urging governments to ensure that tourists observe the principles and purposes of the Antarctic Treaty and Recommendations, including the necessity to inform a station 24 to 72 hours in advance of expected arrival, that all tourists comply with any restrictions imposed by the station manager, that visitors not enter Specially Protected Areas, and that they respect historic monuments.*

  VII-4: Effects of Tourists and Non-Governmental Expeditions in the Antarctic Treaty Area, *urging governments to ensure that the provisions of the Treaty and subsequent recommendations relating to the conservation of Antarctic fauna and flora are applied to all visitors to the Treaty area.*

  VIII-9: Effects of Tourists and Non-Governmental Expeditions in the Antarctic Treaty Area, *urging governments to ensure that tourists are aware of the "Statement of Accepted Principles and the Relevant Provisions of the Antarctic Treaty," urging governments to ensure that tour groups report their activities within the Treaty area and requesting tour operators, except in an emergency, only to visit stations for which they have permission and only to land within Areas of Special Tourist Interest.*

The "Statement of Accepted Principles" *includes the following:*

- *The killing, wounding, capturing or molesting of any mammal or bird is prohibited except in an emergency;*
- *Every effort shall be made to minimize harmful interference with the normal living conditions of any native mammal or bird;*
- *Fur Seals and Ross Seals are Specially Protected Species;*
- *Certain areas of outstanding scientific interests have been designated as Specially Protected Areas to preserve their unique natural ecological system. No person may enter such an Area except by special permit;*
- *No species of animal or plant not indigenous to the Antarctic Treaty Area may be brought into the Area except by permit;*
- *Every effort should be made to prevent damage or destruction to any historic monument;*
- *Permission should be sought in advance to visit Sites of Special Scientific Interest, which have been set aside to allow for scientific*

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investigations free from accidental interference;

- *Organizers of tourist or nongovernmental expeditions should furnish notice as soon as possible, through diplomatic channels, to any government whose station the expedition plans to visit. Any government may refuse to accept a visit to its station or may lay down conditions upon which it would grant permission.*

Recommendation VIII-9 *also includes the following* "Guidance for Visitors to the Antarctic":

- *Avoid disturbing wildlife, in particular do not:*
  - *walk on vegetation;*
  - *touch or handle birds or seals;*
  - *startle or chase any bird from its nest;*
  - *wander indiscriminately through penguin or other bird colonies.*
- *Litter of all types must be kept to a minimum. Retain all litter (film wrappers, tissue, food scraps, tins, lotion bottles, etc.) in a bag or pocket to be disposed of on board your ship. Avoid throwing tin cans and other trash off the ship near land.*
- *Do not use sporting guns.*
- *Do not introduce plants or animals into the Antarctic.*
- *Do not collect eggs or fossils.*
- *Do not enter any of the Specially Protected Areas and avoid Sites of Special Scientific Interest.*
- *In the vicinity of scientific stations, avoid interference with scientific work and do not enter unoccupied buildings or refuges except in an emergency.*
- *Do not paint names or graffiti on rocks or buildings.*
- *Take care of Antarctic historic monuments.*
- *When ashore, keep together with your party.*

X-8: Effects of Tourists and Non-Governmental Expeditions in the Antarctic Treaty Area, *urging that non-governmental expeditions carry adequate insurance; that commercial tour operators, to the extent practicable, carry tour guides with experience in Antarctic conditions who are aware of the Agreed Measures for the Conservation of Antarctic Fauna and Flora and for the protection of the Antarctic environment; that commercial aircraft operators be informed that overflight activity exceeds existing capabilities for air traffic control, communications and search and rescue and such overflight activity exceeds the capacity of governments' Antarctic operations to respond adequately to an unplanned emergency landing.*

or environmental damage, than others, a global regulatory solution is unlikely to be practical.

It would be hard to view the pertinent parts of the Antarctic treaty and subsequent recommendations (see box page 99) as anything but liberal and reasonable. What remains to be seen is what evolves in the future, and whether the reasonable nature of these terms and recommendations will still be appropriate if Antarctic tourism grows substantially.

Some have argued that Antarctica should be made a wilderness sanctuary barred to both scientist and tourist. It is this author's opinion that this is both impractical and runs contrary to the basic principal that man should be free to travel as he pleases, providing he does not infringe on the privacy, rights, or safety of others.

In seeking to monitor or regulate tourism in Antarctica, it is hoped that the right of the individual to visit Antarctica will continue to be respected. Furthermore, it is to be hoped that any future regulations encourage those forms of tourism that are the safest and most protective of the Antarctic environment.

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Protecting the Antarctic Environment

by Gerald S. Schatz

Majestic, forbidding, fabled, and (depending on your point of view) little touched by human presence, Antarctica invites environmental controversy. The evocative symbols are there: grandeur; strikingly beautiful bird life; seal and whale populations recovering from depredations of many years ago; stratospheric ozone depletion; an expanding fishery; rumors (no more than that) of mineral wealth; and the occasional detritus of scientific stations.

Too often lacking in discussions of Antarctic environmental protection are fact, a sense of scale, a sense of what is significant, and, most surprising, a sense of environmental values—what is to be safeguarded in the Antarctic, why, and then how?

Restating the obvious sometimes restores valuable perspective: war dwarfs normal environmental offenses. Accordingly, from the standpoint of environmental protection, the overarching value to be safeguarded in the Antarctic is the Antarctic Treaty—by which nations representing most of the world's population have agreed, however they may disagree on their other Antarctic interests, to keep the area south of 60 degrees South latitude free of military conflict and nuclear explosions. The treaty's consultative procedures have given rise to collateral environmental protection measures; and to additional, separate conventions for protection of seals, and for managing the Antarctic fishery (chiefly, but not exclusively, the krill fishery).

An important part of the Antarctic Treaty's political glue is the understanding that, while ultimate Antarctic rights of claimant nations are not acknowledged and not acted upon, they are nevertheless not foreclosed. Such mutual forbearance is not easily renegotiated. So nurturing the Antarctic Treaty System is far more likely to be environmentally protective than is the advocacy of ostensibly stronger substitute regimes (for example, a world park, or United Nations administration).

A principal environmental value of the Antarctic is the region's roles in planetary geologic, oceanic, atmospheric, and climatic processes. Responsible human stewardship of the planet requires far more understanding of these processes. Investment in this kind of science, and in the logistics to support it (see article page 80) fostered four decades of international scientific cooperation, improved the understanding of climate dynamics, and made possible the detection and intensive study of the Antarctic ozone hole. A major value is basic understanding of the region itself, including its relatively few ecosystems.

Against this background, the requisite elements of Antarctic environmental protection policy are evident: sustain the treaty, maintain the science (at no unnecessary risk to personnel), protect the place, and do not compromise the science. The first and second of these are clear enough, the third and fourth not quite clear-cut.

These were not big issues in the expeditionary days of the Antarctic. The science did not depend on fine point, parts-per-billion measurements; little harm was seen in local trash dumping; the areas of human impact were few and small; and the principal problems were those of access and survival.

Shift of Emphasis

As Antarctic science evolved, and emphasis shifted from reconnaissance to far more formal and detailed research, environmental issues drew increasing attention. The Scientific Committee on

Antarctic Research (SCAR), of the International Council of Scientific Unions (ICSU), began in the 1960s to recommend environmental safeguards, subsequently adopted by the Antarctic Treaty's consultative parties.

The United States had backed the work of a large community of Antarctic environmental scientists. In 1971, the U.S. National Science Foundation (NSF), which had recently become the lead agency for the U.S. Antarctic Program, sponsored a major colloquium on problems of conservation in Antarctica. Among the concerns: litter and waste-disposal, as might be expected, and, as was not expected, interference with science itself. By this time, Antarctic science had become precise enough to be vulnerable to air pollution and contamination of study sites. From these perceptions grew the establishment of protected sites of special scientific interest.

Antarctic logistical engineering evolved, and there were efforts to minimize human impact. What was protective was not always a matter of certainty, and there were false starts. A wastewater-treatment plant was brought to the Antarctic, but plans for its use were cancelled when it was found that chemicals that would be released by the plant would do more environmental damage than the small amount of human sewage released to the ocean, and that the chemical release would contaminate scientific studies as well. An incinerator turned out to be a voracious oil-burner. Still, a good deal has been done:

- *The NSF undertook a comprehensive study of the environmental impact of its entire Antarctic program. Impacts were found to be transient and limited—the presence of a few stations and temporary camps.*

- *The United States passed and rigorously enforces its Antarctic Conservation Act, prohibiting U.S. citizens from touching or even getting close to Antarctic birds, mammals, and plants, except for scientific purposes, and then only under a very restrictive permit system.*

- *The United States has begun seeking ways to limit adverse environmental impacts of Antarctic tourism [see article page 93].*

- *What otherwise would be waste heat from diesel generators is used at McMurdo Station to distill fresh water from seawater; at the Amundsen-Scott South Pole Station to supply fresh water from ice; and at Palmer Station to heat buildings. Less fuel is used, and atmospheric emissions are cut.*

- *Where possible, solar power and wind power are used for automated observatories. These technologies have not been found adequate for support of whole stations.*

- *A new oil separator at McMurdo prevents garage lubricants from entering the sewage system, and waste lubricants are shipped back to the United States.*

- *Sewage at McMurdo is diluted with brine to minimize impact.*

- *Old bases and stations are being cleaned. Marble Point Camp was rehabilitated completely. McMurdo utility lines are being consolidated, sprawl is being reduced, and a general site cleanup has been in progress for several years. The most visible problem at McMurdo is the metal dump at Winter Quarters Bay, where steel scrap was put on the ice many years ago and was expected to drift out to sea. The ice did not drift. The scrap froze in place and is being cut apart and staged for shipment back to the United States. Work on that ice is slow and dangerous, but it proceeds.*

- *Metal scrap from McMurdo formerly was dumped in the ocean. Now it is shipped back to the United States.*

- *Solid wastes from field camps are taken back to main bases. If, as in the Dry Valleys,* liquid waste cannot be deposited in deep snow trenches, it, too, is hauled back to main bases.*

- *Each year, hundreds of tons of materials—waste lubricants, metal drums, packing, scrap metal construction waste, broken tools, rubber tires, vehicle parts, supplies, and scientific equipment no longer needed in Antarctica—are shipped back to the United States. In the 1986–1987 season, the cargo ship M/V* Green Wave *took 1,700 metric tons of retrograde cargo out of Antarctica. At the end of the 1987–1988 season, the shipments of retrograde cargo included 16 flat racks, each carrying more than 9 metric tons of scrap metal; more than 500 drums of waste oil and other petroleum products; and 60 large cargo containers of other materials no longer needed there.*

Environmental Protection Plan

Largely ad hoc in earlier days, the U.S. Antarctic Program's environmental protection work is becoming more focused. The program has begun the development of an Environmental Protection Plan, not as a one-shot exercise, but as the framework for continuing effort. As of this writing, the plan is in revision, following external review by environmental specialists. It will include:

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* Unglaciated areas west of McMurdo Sound known as the "Dry Valleys" offer spectacular landscapes of layered mountains rising above barren ground that is often patterned into giant frost polygons.

- *Environmental management planning: periodic, program-wide review is needed to consider the implications of site planning and other support developments that might impinge on science and the environment, to consider the adequacy and implications of environmental studies and monitoring, and to update its environmental protection planning.*

- *Legal review: international environmental law, Antarctic Treaty law, and related domestic law inevitably are "soft law," to accommodate international differences, and cannot be absolute in the manner of traffic ordinances. The U.S. Antarctic Program must respond to an amalgam of Antarctic Treaty obligations, other international commitments, the Antarctic Conservation Act, the National Environmental Policy Act, executive orders, regulations, and other statutes, not the least of which deal with funding and federal agency operations generally. The program is seeking a clear picture of its legal responsibilities.*

- *Environmental assessments and impact studies: anticipating the consequences of decisions is at the core of environmental protection. The law provides for environmental assessments to determine whether proposed major actions will be of significant environmental impact, in which cases impact studies are required. Such studies have been conducted for scientific drilling programs on the Ross Ice Shelf and in the Dry Valleys, and for the U.S. Antarctic Program as a whole. The program is reviewing its procedures to ensure that assessments and impact studies are conducted as required. Additionally, opinions were sought from conservation organizations and other agencies on points to be considered if new information warrants supplementing the current programmatic environmental impact statement.*

- *Environmental awareness: informational and administrative efforts will be increased to ensure that U.S. Antarctic Program participants and visitors understand and meet their environmental responsibilities.*

- *Facilities and logistics: the program must review the adequacy of its facilities and logistics to meet its needs within the overriding criteria of protection of the Antarctic Treaty, the people, the science, and the place. Initially, the emphasis is on waste-management at McMurdo Station, the United States' largest Antarctic support facility. Assessment of McMurdo solid-waste production and alternatives for its management has begun, with the objective of developing an environmentally protective waste-management system.*

Choices for impact mitigation are far from clear. Cutting U.S. Antarctic operations is not an option. It would leave the world without a major capacity for support of vital Antarctic environmental science, and it would cut the U.S. role in maintaining the Antarctic Treaty.

Optimal waste-management technology is subject to question. Several other countries have begun to clean up their Antarctic operations, impressively, but those stations are very small, and their technology is not necessarily suited to year-around operations at McMurdo and at Pole Station. Incinerators and compactors do not always work, and incinerators can pollute.

Carrying all wastes from U.S. Antarctic stations back to the United States would require storage facilities in Antarctica, impose a pollution load from ships in Antarctica, and transfer the disposal problem to the United States. Carrying all wastes from Pole Station to McMurdo would necessitate additional costly airplane flights into and out of the station, where sensitive atmospheric measurements are in progress and will be for many years to come.

Carelessness many years ago left pollutants trapped in a few isolated spots in nearshore sediments at McMurdo; trying to clean them out would only release them to the environment.

In short, engineers can be very good, but cannot work miracles. The U.S. Antarctic Program can do no more and no less than try to be careful, keeping its act as clean as possible, sometimes having to make the best choice from among several not completely satisfactory alternatives.

All that said, it is a lot of effort to deal with what in fact are very small places. Save for its ice runway, nearly all of McMurdo Station, Antarctica's largest scientific station and logistical facility, takes up an area of no more than three or four times the size of an ordinary schoolyard. That sense of scale should temper judgments about environmental impacts. Trash is not pretty, and what has not been cleaned up ought to be cleaned up—in the least harmful way. The presence of an old junk dump does not in itself warrant casting doubt on the efficacy of the Antarctic Treaty. Antarctic environmental protection has to proceed from an understanding of the place and its values. Sentiment alone does not suffice.

Gerald S. Schatz is a research policy analyst on a temporary appointment with ITT Antarctic Services, Inc., Paramus, New Jersey, as environmental policy advisor to the U.S. Antarctic Program. The author is solely responsible for opinions expressed herein.

Selected Readings

Bonner, W. N., and D. W. H. Walton, eds. 1985. *Key Environments: Antarctica.* 381 pp. New York: Pergamon Press.

Parker, B. C., ed. 1978. *Environmental Impact in Antarctica: Select Papers by Scientists Addressing Impact Assessment, Monitoring, and Potential Impact of Man's Activities in the Antarctic.* Blacksburg, Virginia.: Virginia Polytechnic Institute and State University.

Quigg, P. W. 1983. *A Pole Apart: The Emerging Issue of Antarctica.* A Twentieth Century Fund Report. 299 pp. New York: New Press, McGraw-Hill Book Company.

U.S. National Science Foundation. 1980. *U.S. Antarctic Program Final Environmental Impact Statement.* Washington, D.C.: National Science Foundation.

concerns

Environmental Threats

in Antarctica

Barrels in dump area at U. S. McMurdo Base, photographed in late December, 1987. Water run-off enroute to McMurdo Sound passes under these barrels, which are sometimes used to store waste oil. (Photo courtesy of Greenpeace)

by Paul S. Bogart

As you approach the hut from where Robert Scott launched his fateful attempt to reach the South Pole in 1911, reminders of the expedition's presence are everywhere. Nails lie scattered about the beach, wooden crates full with tins of cocoa and biscuits are stacked around the hut. Preserved in an environment in which the processes of biodegradation can take centuries, it is easy to forget that it has been more than 75 years since Scott's tragic death.

Eighteen miles across the sea ice of McMurdo Sound, there are other traces of the human presence: truck tires, sections of pipe, and drums of oil are scattered haphazardly about—some are punctured and leaking into the porous Antarctic soil. Pieces of discarded trucks and other metal materials lie along the shoreline which surrounds an ocean floor littered with the refuse of 30 years of ocean dumping. These are not the remnants of the age of Antarctic exploration, however, but rather the result of the United States Antarctic Program (USAP).

Waste disposal methods like these are not unique to the United States. Since 1959, the Antarctic Treaty nations have dedicated themselves to increased understanding of the fragile Antarctic environment, but if many of the current practices continue, they may provide one of its greatest threats.

The focus of man's interest in the Antarctic has changed dramatically since explorers like Scott and Amundsen stood on the continent at the turn of the century. Man has come to appreciate the opportunity Antarctica offers for scientific study. Antarctica is a fascinating storehouse of information about the world's geological history. It has unique wildlife, whose habitat is relatively free of human interference, and as close to its original state as any on the planet. The continent's purity, and its freedom from most of the pollution that pervades the rest of the world, makes it a valuable site from which to monitor other global variables—a baseline for monitoring how humans are damaging their environment.

It is important for science and scientists that the Antarctic remains the pure environment that it is at the present. However, there are challenges presently facing the Antarctic that are bound to have a dramatic adverse effect on the quality and orientation of science conducted there.

The reality of environmental protection in the Antarctic has not always matched up to the claims which the Antarctic Treaty nations have made for it. The treaty states have frequently proclaimed their concern for the protection of the environment. It may be true that their rules have been instrumental in preventing some severe abuses to the Antarctic environment. It is also true, however, that the measures established under the treaty system have not always worked as they were intended, and that, in some cases, there have been deliberate and knowing breaches, if not of the letter of the regulations, then certainly of their spirit.

In this respect, it is constructive to look at several examples where protection of the Antarctic environment has clearly been a matter of secondary importance. These examples constitute grave cause for concern about the future, when the Antarctic will face increasing human pressures.

Waste Disposal

The effects of 30 years of ocean dumping in McMurdo Sound would not be apparent to a visitor at McMurdo, or even to personnel on the base. Dr. Paul K. Dayton dove in the Winter Quarters Bay section of the Sound throughout the 1960s and early 1970s, however, and reported that, "In 1964, Gordy and I made several dives there and found great piles of trash (old vehicles, hose, and so on) and what appeared to be frozen organic material . . . then, in 1974, we found Winter Quarters Bay to be essentially dead, the sediment so full of DFA (diesel fuel additive) it almost appeared combustible! Clearly there was a massive spill of some sort and I doubt if that amount of DFA will be broken down in the near future."[1]

Although the dumping of solid waste into McMurdo Sound has been discontinued, the attitude behind the policy remains. Practices like open burning of combustible waste and the discharge of liquid waste into the sea continue. These practices simply transfer the impacts of the human presence, but do nothing to minimize them.

The new maceration equipment recently put into operation at McMurdo grinds liquid waste so that it is more easily dispersed in the water, but does nothing to treat it. Open burning may provide a quick fix to reduce the total volume of combustible waste present on site, but it is anything but a solution. Particulate matter from the burn is spread throughout the area, and could compromise air quality. Additionally, the practice of separating plastics, rubber, batteries, and other materials that present hazards when incinerated is either not encouraged, or simply not enforced. Several site visits conducted by Greenpeace throughout 1987 and 1988 documented the presence of such materials in the dump.

The Antarctic Code of Conduct provides recommendations for minimizing man's impact on the Antarctic environment. The practice of open burning, as well as the presence of batteries, plastics, and truck tires all violate this code. The National Science Foundation (NSF) administers the United States Antarctic Program. It is often difficult to determine official policies of NSF. Repeated attempts by Greenpeace to obtain written policy regarding waste disposal practices have been unsuccessful. Officials at NSF headquarters in Washington, D.C., have explained that the policy is kept at McMurdo, while McMurdo officials suggested we try Washington.

Communication between USAP administrators and employees may be just as inconsistent and account for much of the problem. There are no signs prohibiting the disposal of plastics and other hazardous wastes in the dump, and, until this year, the absence of a fence permitted access by anyone, and caused wind scatter of materials.

The United States Research Program is by no means the only nation with waste disposal problems. Tourists visiting the Argentine Esperanza base have documented the dumping of waste along the shoreline, a practice which degrades the marine environment and forces penguins in the nearby rookery to traverse the dump on their way to and from the water.

An English biologist, Dr. Ron Lewis-Smith, began a 10-week visit to Australia's Casey station and the nearby abandoned Wilkes station, in February 1986. The report he wrote as a result of that visit casts Australia's waste management in a very unfavorable light.[2]

The report notes that Wilkes appears as it was in 1969, when it was abandoned in favor of Casey—"tinned and bottled food, machine parts, building materials, chemicals (including more than 200 boxes of tinned caustic soda spilling their

contents onto the snow), metal drums, flares, and even explosives were scattered over at least a square kilometer.

"At Casey station, rubbish was collected in an open trailer and dumped in the station's tip twice daily, irrespective of wind force and with no separation of non-combustible, toxic, or hazardous materials, including petrol. Skuas had been found dead around the tip, and scavenging birds had removed food scraps and dropped parts over a wide area—including unburnt poultry bones, which could transmit viral infections to nearby penguin colonies. During burning of rubbish at the dump, scraps of paper and soot regularly descended on the nearby Site of Special Scientific Interest (SSSI)."

It would be unfair to imply that Casey and McMurdo are the only bases at which such problems exist. However, it does indicate that there is, at least in these cases, a wide gap between the standards expected by the treaty system, and the standards actually maintained in Antarctica.

The French Airstrip at Pointe Geologie

The French government decided in the 1970s to construct an airstrip at their Dumont d'Urville base. The plan eventually adopted, when construction began in the early 1980s, was to level a chain of islands in the Pointe Geologie Archipelago, using the spoil to fill in the shallow channels between them, constructing a hard-rock airstrip along the alignment thus created.

The plan aroused considerable opposition from the international environmental community, and also from within the French scientific community, primarily because of the potential damage to the fauna of the area, considered to be among the richest of any area in the Antarctic. In addition to concern expressed about inadequacies in the assessment of the environmental impact of the airstrip, the international environmental community brought to public notice a breach of the Agreed Measures, which they alleged had occurred during the construction program.[3]

The response of the Antarctic Treaty Consultative Parties (ATCPs) to the allegations was fairly muted. At a treaty meeting in Brussels in April, 1985, however, no country was willing to have the matter formally discussed. Some delegates to the meeting argued that it was important for the unity of the treaty nations to be demonstrated, and that they could not afford a debate on such a potentially divisive issue. Environmentalists fear that this argument could be used, and probably will be used, in future circumstances where such breaches are alleged. When, with clear evidence of a breach, there is an almost unanimous desire on the part of the ATCPs to avoid discussion of it, the value of the Agreed Measures as a mechanism for environmental protection must be called into question.

The Failure of Specially Protected Areas

The Agreed Measures, Article VIII, designate "Specially Protected Areas" (SPAs) in order to protect the "unique natural ecosystems" of areas of outstanding scientific interest. This article specifically prohibits the collection of native plants and the driving of vehicles in SPAs. At a treaty meeting in 1970, entry into an SPA without a permit was prohibited, and this condition was consolidated into the Agreed Measures in 1975. While this process was occurring, both the Soviet Union and Chile were planning on building a base in the Fildes Peninsula SPA, on King George Island in the Antarctic Peninsula.

Once again, rather than raise what might become a contentious issue, the ATCPs responded by amending the area of the SPA to accommodate the area required for the bases. The designation of the Fildes Peninsula as a SPA was, in part, due to the presence of a series of biologically important melt-lakes in the area. When Greenpeace visited the Chilean Teneiente Marsh/Presidente Frei station in April of this year, it was discovered that Chile had been using one of the lakes as a rubbish dump. Greenpeace expedition Coordinator Dr. Maj De Poorter commented, "this is an outrageous use for a lake that was once considered worthy of the highest level of protection."

It would be impossible in an article of this scope to completely cover all the issues that face the Antarctic at present. Unregulated tourism, overfishing, and minerals exploitation all must be addressed in order to effectively protect this last great wilderness (ozone depletion is a separate, world-wide problem). I have attempted, through the use of examples, to underscore the general unwillingness of the ATCPs to criticize each other. Within the current context of waste disposal practices that threaten local habitats, construction and logistic considerations that take precedent over a fragile and unique ecosystem, and nations unable or unwilling to confront other treaty nations when violations are apparent or documented, the prospect of minerals development becomes especially frightening.

The habitat destruction and degradation that have occurred so far has been at bases dedicated solely to understanding this continent. The performance of the treaty states in other areas of environmental protection does not give environmentalists confidence that mineral activity will be regulated any more stringently, nor is it guaranteed that a minerals agreement will be able to weather possible conflicts over resources in other parts of the world. This underlies the Greenpeace position that mineral exploitation should not be permitted to occur.

Greenpeace holds a different view for the future of the Antarctic. We advocate the establishment of a World Park to more completely ensure the protection of this last unspoiled wilderness. Under the World Park proposal, the Antarctic would be a zone of peace, free from militarization, and dedicated to the complete protection of wildlife and peaceful scientific

Antarctic Strategic Concerns

Although there has been much argument over the significance or insignificance of Antarctica in strategic terms, this discussion has been largely theoretical. The fact is that Antarctica has been used in the past for strategic purposes and the conduct of warfare. German submarines operated in Antarctic waters during World War II, inflicting heavy damage on the merchant fleets and fishing vessels of a number of countries.

The German and Japanese interests in Antarctica during the war were enormously influential in the development of territorial claims to that continent. The Norwegian claim materialized at the moment when it was felt that a potential German claim had to be stopped. Germany and Japan had been following U.S. policy toward Antarctica very closely, with particular regard to whether the United States was planning to make a claim of its own, an idea that in fact was actively considered at the time. The Soviet Union had occasionally looked into a similar alternative.

It is also interesting to remember that the Chilean decree of 1940, which specified the limits of Chile's Antarctic claim, was directly prompted by a diplomatic initiative of President Roosevelt, who was looking for additional ways to prevent a German claim or the establishment of a German base in Antarctica.

It is not an exaggeration to conclude, therefore, that, as a consequence of growing interest in the issue of the strategic uses of Antarctica, greater emphasis was placed on sovereign claims. Nor is it mere chance that the provisions of the Antarctic Treaty that freeze the question of sovereignty have been coupled with provisions on demilitarization and peaceful uses. The attainment of one objective necessarily requires the achievement of the other. . . .

The geographical distribution of Antarctic stations by the two [super] powers was also to some extent an expression of the interest in establishing a presence throughout the continent, a policy that was not unrelated to strategic interest or to the eventual territorial claims that such powers could ultimately decide to put forward. Both the United States and the Soviet Union actively considered in the past the policy of making territorial claims in Antarctica, and this position has been safeguarded by the Antarctic Treaty in describing the two countries as those having "a basis of claim."

It is not difficult to foresee that if for any reason the Antarctic Treaty arrangements were to collapse, and the strategic interests of the major powers revived, a likely consequence might be that these potential territorial claims would be made effective, thereby introducing additional complications in the already complex Antarctic scenario.

The possibility of conducting nuclear explosions in Antarctica had never been explicitly ruled out by either of the major powers, nor had the eventual disposal of nuclear wastes in the continent. While there were continued references to peaceful uses, it is well known that such uses have been interpreted by the major powers as being compatible with the conducting of peaceful nuclear explosions. It was only through an active diplomatic effort undertaken during the negotiation of the Antarctic Treaty that such steps in the domain of nuclear policy were specifically prohibited and remain so until this day.

—from Francisco Orrego Vicuna, Antarctic conflict and international cooperation. In *Antarctic Treaty System: An Assessment.* The National Academy Press, 1986.

cooperation. The principles of a World Park are, in fact, much closer to the original intent of the Antarctic Treaty than some nations' current practices.

Paul S. Bogart is U.S. Antarctic campaign coordinator, Greenpeace, Washington, D.C.

Endnotes

[1] Letter from Dr. Paul K. Dayton to Dr. Richard Williams, National Science Foundation. Nov. 21, 1983, Comments on Raytheon Water Quality Report.
[2] Sydney Morning Herald, 12 and 13 February 1986.
[3] ECO Vol. 22, No. 1 and 3, January, 1983, Wellington, New Zealand; ECO Vol. 23, No. 3 and 4, July, 1983, Bonn Federal Republic of Germany; ECO Vol. 26, No. 1 and 2, January, 1984, Washington D.C. USA; ECO Vol. 30, No. 1, April, 1985, Brussels, Belgium.

Errata

Oceanus Vol. 31, No. 1, Spring 1988
U. S. Marine Sanctuaries issue

Because of a printer's error, the title and author's name were omitted from the top of the article that begins on page 82. It should have read:

International Networking of Marine Sanctuaries
by Douglas B. Yurick

At right center of map on page 7, Gray Reef NMS should have read: Gray's Reef NMS.

The title at the top of page 14, National Oceanographic and Atmospheric Administration . . ., should have read The National Oceanic and Atmospheric Administration . . . .

letters

To the Editor:

Considerable concern has been expressed in recent years at the indiscriminate and unregulated naming of undersea features that often get into print in articles submitted to professional journals, or on ocean maps and charts, without any close scrutiny being made concerning their suitability, or even whether the feature has already been discovered and named, albeit in another country and possibly language.

The Intergovernmental Oceanographic Commission (IOC) at its 14th Assembly in March 1987, and the International Hydrographic Organization (IHO) at its 13th Conference in May 1987, adopted motions in which they "strongly encourage marine scientists and other persons in the member states wishing to name undersea features, to check their proposals with published Gazetteers of Undersea Feature Names, taking into account the guidelines contained in the IHO-IOC publication, *Standardization of Undersea Feature Names*, to submit all proposed new names for clearance, either to their appropriate national authority or, where no such national authority exists, to the IOC or IHO, for consideration by the General Bathymetric Chart of the Oceans (GEBCO) Sub-Committee on Geographical Names and Nomenclature of Ocean Bottom Features, which may advise on any potentially confusing duplication of names."

Copies of the IHO-IOC publication *Standardization of Undersea Feature Names* can be obtained free-of-charge from the International Hydrographic Bureau, B.P.445, MC 98011, Monaco Cedex.

The most comprehensive world Gazetteer of Undersea Features is published by the United States Defense Mapping Agency, on behalf of the U.S. Board on Geographic Names (BGN) Advisory Committee on Undersea Features (ACUF). This advisory committee meets regularly to deliberate on proposed, contested, or already-published-but-unreviewed names, and to update the Gazetteer.

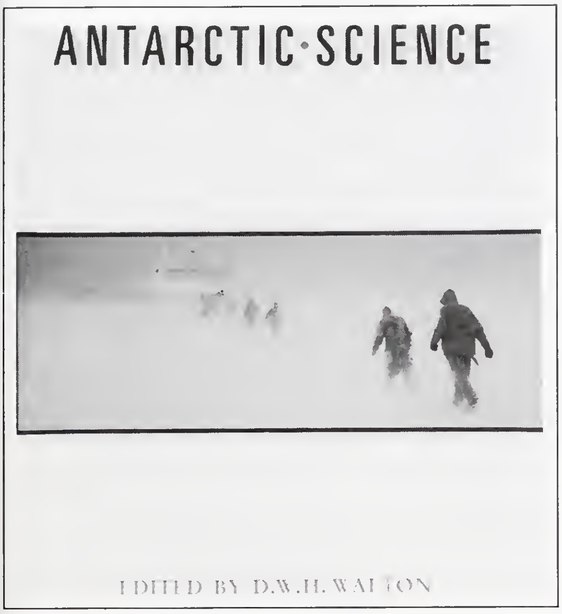
The anarchy that presently prevails in the naming of undersea features would not be permitted in the fields of biological or geological systematics, in both of which disciplines great care is taken to maintain order and eliminate duplication in the selection of names.

In our opinion, great care should be taken by detailed checking of appropriate reference books, and by enquiry to ensure that a feature has not already been named in the technical literature of any country (or in any language). Only then should a new name be chosen, and the dictates of any such choice should be historical courtesy, significant commemoration, and good taste (in that order).

The acceptance of this suggestion would help to reduce some of the existing confusion in the proliferating wealth of names that continue to appear in the scientific literature.

Sir Anthony Laughton
Chairman
Joint IOC-IHO Guiding Committee for the GEBCO
Institute of Oceanographic Sciences
Wormley, England

book reviews



***Antarctic Science*, D. W. H. Walton, ed. 1987. Cambridge University Press, Cambridge, England. 280 pp. $39.50.**

This extremely informative book, written by scientists from the British Antarctic Survey in Cambridge, England, reviews the major international developments in Antarctic science from its early beginnings in the age of Captain Cook (middle 1700s) to the present. In the preface, written by the editor D. W. H. Walton, note is made of the recent upsurge in public interest in the continent fueled by expectations that rich and untapped resources—in the form of krill, fish, oil, gas, and metallic ores—exist in the region.

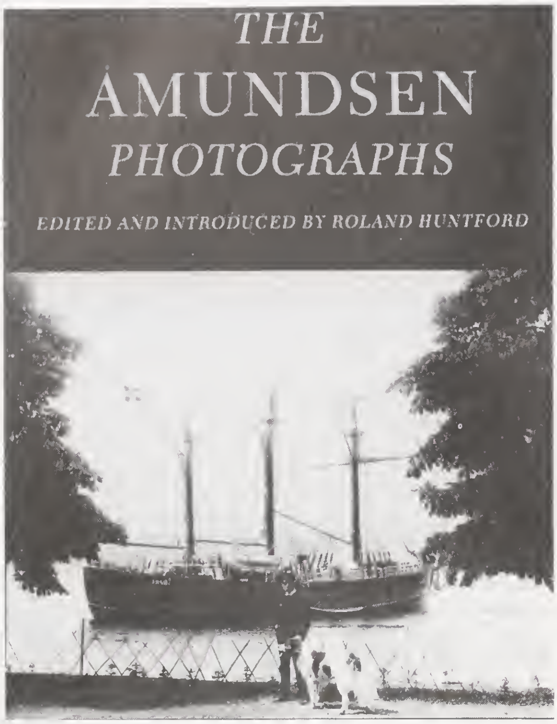
Walton states that "many of the present economic assumptions (concerning Antarctica) are based on little or no data. . . ." He asks, "Why then, after more than 25 years of research, are the data necessary for considered and accurate judgements lacking? Have any substantial contributions to science been made by research in Antarctica?" Indeed, the answer to the latter question is a resounding yes. The book describes some of the difficulties of conducting science in the inhospitable climate of the region as partial answer to the first. The editor notes that the major outcome of conducting this science "has been the exceptional degree of international collaboration in programmes and a willingness to help others. This has transcended the political difficulties that have characterised world history during the period."

The book's authors examine individually the three major areas of science—biology, the earth sciences, and atmospheric science. They highlight the principal achievements of the last 25 years, thus providing an up-to-date account of both the continent, which comprises almost 10 percent of the land surface of the globe, and the vast extent of the Southern Ocean surrounding it. Following an introduction by Sir Vivian Fuchs, David Walton examines the history, geography, politics, and science of the continent. In Part II, Inigo Everson considers life in a cold environment; in Part III, Chistopher Doake looks at Antarctic ice and rocks; and John Dudeney discusses the Antarctic atmosphere in Part IV. Richard Laws concludes with a discussion of the Antarctic Treaty, which was ratified in 1961 and comes up for possible review in 1991.

The historical section abounds with interesting items. For example, in 1840 the United States Exploring Expedition led by Charles Wilkes was "successful despite itself. Badly organized, poorly equipped and with rotten ships, Wilkes still managed to follow the Antarctic coast for nearly 2,400 kilometers. On his return, he was court-martialled by the United States for his conduct as Commander, whilst the Royal Geographic Society awarded him a gold medal for his achievement! Congress was niggardly in voting funds for the writing-up of the scientific data and much of great importance was lost."

The text of *Antarctic Science* is complemented throughout with many fine illustrations, including fascinating archival photographs of the early days of exploration and many beautiful color photographs of the region. There are three appendices: one, The Antarctic Treaty; two, major symposia and conferences with which the Scientific Council for Antarctic Research (SCAR) is associated; and three, further information on Antarctic science. There is a select bibliography and an index. I found the volume extremely useful as a reference source in putting together this issue of *Oceanus*. The book will appeal not only to scientists, but to all interested in the further development of Antarctica.

Paul R. Ryan
Editor, *Oceanus*



***The Amundsen Photographs*. Edited and Introduced by Roland Huntford. 1987. The Atlantic Monthly Press, New York. 199 pp. $35.00.**

The great Norwegian explorer Roald Amundsen is described by Roland Huntford in his introduction as "one of those driven souls who have shaped our century." Amundsen disappeared in 1928 while attempting to recover an Italian expedition in the Arctic. His estate was left in confusion and his many hand-colored lantern slides, which he had used on his extensive lecture tours, were thought to have been lost. Nearly 60 years later, in 1986, the widow of Amundsen's nephew discovered a packing crate marked "Horlick's Malted Milk" stowed in the attic of her Oslo home. Inside were more than 200 of Amundsen's original slides (see cover photo for an example).

More than 150 of these images are reproduced in *The Amundsen Photographs*, an illustrated chronological tour of Amundsen's unrivaled achievements in polar exploration. His first major feat was the successful navigation through the North West Passage—the legendary shortcut across the top of North America—in 1903. Perhaps the accomplishment for which he is most recognized is as the first man to reach the South Pole in 1911. In 1918, Amundsen became the second man to sail through the North East Passage—the long-sought seaway along the northeast coast of Russia, known also as the Maud Expedition. With these three major voyages, Amundsen became the first, and to this day, the only, man to have circumnavigated the Arctic.

Roland Huntford's extensive introduction, which is divided into three parts, chronicles each of Amundsen's voyages. The simple, yet beautiful and unique images are set in the context of Amundsen's life and explorations. Much more than a mere description of the expeditions, the book explores Amundsen's own tales of life and travel in the Arctic. The captions are drawn from the explorer's notes and journals, and reveal a great deal about Amundsen's character and motivation. For example, Amundsen was always intrigued with the highly specialized lifestyle of Arctic peoples; he studied extensively the adaptations of the Eskimos to their harsh, unforgiving environment. Amundsen did not consider the Eskimos as savages; rather, he was intrigued with their abilities to survive and develop a unique culture in the formidable Arctic conditions. His own words reveal a keen insight, a fervent energy, and a passion for learning. They reflect, too, the ideas of a true anthropologist.

Amundsen's lantern slides themselves are a curious study of early 20th Century photography. Many were hand-colored, as 35mm color film was still experimental in Amundsen's day. The slides were bulky, yet fragile; the cameras, too, were cumbersome. Yet, Amundsen and his companions carried their equipment for countless miles across the ice. They took the pictures themselves, spontaneously—the quality of their work was not professional, but "undoubtedly that of the snapshot." Nonetheless, the photographs are valuable testimony to the events that took place; the explorers registered details of their travels as they saw them. The outcome is a poignant blend of immediacy, authenticity, and humility, all of which are representative of Amundsen's own personal style.

Four years after his completion of the North West Passage, Amundsen was determined to reach the North Pole. Both the American and Danish explorers, Robert Peary and Dr. F. A. Cook, claimed to have achieved that goal as Amundsen was preparing to launch his journey. Huntford relates Amundsen's dismay, and his ultimate decision to aim for the South Pole instead. There were additional complications, however, for at the same time, Captain Robert Falcon Scott, an officer in the British Navy, was preparing to lead the English attempt on the South Pole. For Amundsen and his Norwegian party, it was a race from the start. Their expedition was undertaken completely unbeknownst to the British.

After sailing from Norway on the newly refitted vessel, *Fram*, Amundsen's real test came when he and his men reached the edge of the Antarctic continent. They had to survive the long, dark polar winter before setting out for the Pole. When they got underway in October, 1911, they forged their way on skis across completely unexplored, uncharted terrain. They encountered mountains, ice, crevasses, fog, and blizzards; but their preparation had been meticulous—Amundsen had learned his lessons in polar survival well. He was plagued by the thought of Scott, and determined to reach the Pole first. With his company of 4 men and 54 dogs, Amundsen claimed the South Pole on December 15th, 1911.

Fame was bestowed on Amundsen when he returned to civilization. But in one of his later journals, he expressed his bitter disappointment in never reaching the North Pole, at the opposite end of the globe.

> *I cannot say . . . that I stood at my life's goal. I believe no human being has stood so diametrically opposed to the goal of his desires as I did. . . . The North Pole had attracted me since the days of my childhood, and so I found myself at the South Pole. Can anything more perverse be conceived?*

Whatever Amundsen's disappointment, he nevertheless won the "longest ski race in history." His journey was not only one of exploration, it was "a triumph of forethought, technical preparation, and

learning what the Eskimos had to teach about survival in a polar environment."

Most of Amundsen's film from the South Pole expedition was damaged or destroyed. The photographs reproduced in this volume were taken by one of his companions, Olav Bjaaland, who documented the people, places, and events of the expedition using only his folding pocket Kodak. His photographs capture the simple essence of the journey—the true grit of the men, the starkness of the polar ice, the dogs (who were so important to the success of the expedition), and the final arrival at the Pole. They are the only visual record of this last great exploration into the unknown corners of the Earth.

Huntford sums up Amundsen's achievements well:

> *Amundsen was no prosaic investigator. He was a dreamer and a man of action. He was pre-eminent in a generation that saw the shrinking of the empty spaces on the map. His lantern slides encapsulate the achievements of a remarkable man. They summarize the end of the classic age of terrestrial discovery, when the polar regions were the last great blanks on the surface of the globe, and men moved under their own power, with ski, sleds, and dogs. Afterwards came the leap into space. It is a new aspect to a famous story.*

The Amundsen Photographs is a beautiful and unique tribute to the inspiring accomplishments of Amundsen the voyager, the seeker, the humanitarian. It also is a fitting testament to native cultures of old and to the classic age of exploration.

Lucy W. Coan
***Oceanus* Intern**

Books Received

Biology

Advances in Marine Biology, Volume 24 edited by J. H. S. Blaxter and A. J. Southward. 1987. Academic Press, San Diego, CA 92101. 473 pp. + xii. $48.00.

Approaches to Marine Mammal Energetics edited by A. C. Huntley, D. P. Costa, G. A. J. Worthy and M. A. Castellini. 1987. The Society for Marine Mammalogy, Lawrence, KS 66044. 253 pp. + xviii. $15.00.

The Biology of Fish Growth by A. H. Weatherley and H. S. Gill. 1987. Academic Press, San Diego, CA 92101. 443 pp. + xii. $65.00.

Marine Organisms as Indicators edited by Dorothy F. Soule and G. S. Kleppel. 1988. Springer-Verlag, Secaucus, NJ 07094. 342 pp. + xii. $98.00.

Martinique Revisited: The Changing Plant Geographies of a West Indian Island by Clarissa Thérèse Kimber. 1988. Texas A&M University Press, College Station, TX 77843. 458 pp. + xx. $74.50.

The Natural History of Nautilus by Peter D. Ward. 1987. Allen & Unwin, Winchester, MA 01890. 267 pp. + xiii. $34.95.

Reproduction of Marine Invertebrates Volume IX: General Aspects: Seeking Unity in Diversity edited by Arthur Giese, John Pearse, and Vicki B. Pearse. 1988. Blackwell Scientific Publications, Palo Alto, CA 94301. 712 pp. + xxii. $50.00.

Seabirds: Feeding Ecology and Role in Marine Ecosystems edited by J. P. Croxall. 1987. Cambridge University Press, New Rochelle, NY 10801. 408 pp. + viii. $59.50.

Toward a New Philosophy of Biology: Observations of an Evolutionist by Ernst Mayr. 1988. Harvard University Press, Cambridge, MA 02138. 564 pp. $35.00.

Earth Science

Antarctica: Soils, Weathering Processes and Environment by I. B. Campbell and G. G. C. Claridge. 1987. Developments in Soil Science 16, Elsevier Scientific Publishing Company, New York, NY 10017. 368 pp. + xxxviii. $116.00.

Introduction to Oceanography, Fourth Edition by David A. Ross. 1988. Prentice-Hall, Englewood Cliffs, NJ 07632. 478 pp. + xii. $35.33.

Theories of the Earth and Universe: A History of Dogma in the Earth Sciences by S. Warren Carey. 1988. Stanford University Press, Stanford, CA 94305. 413 pp. + xviii. $45.00.

Thermodynamics of the Carbon Dioxide System in Seawater, Report by the carbon dioxide sub-panel of the joint panel on oceanographic tables and standards. 1987. Unesco technical papers in marine science number 51, UNESCO, Paris, France. 55 pp. + v. Free.

Environment

The Cassandra Conference: Resources and the Human Predicament edited by Paul R. Ehrlich and John P. Holdren. 1988. Texas A&M University Press, College Station, TX 77843. 330 pp. + xi. $14.95.

Chesapeake Bay Environmental Data Directory compiled by Dan Jacobs, Daniel Haberman, David Smith, David Swartz, Elizabeth Sigel, and Michael Adams. 1987. Maryland Sea Grant Program, College Park, MD 20742. Free.

Comparison Between Atlantic and Pacific Tropical Marine Coastal Ecosystems: Community Structure, Ecological Processes, and Productivity edited by Charles Birkeland. 1988. Unesco reports in marine science number 46, UNESCO, Paris, France. 262 pp. Free.

Integrated Agriculture-Aquaculture in South China: The Dike-Pond System of the Zhujiang Delta by Kenneth Ruddle and Gongfu Zhong. 1988. Cambridge University Press, New Rochelle, NY 10801. 173 pp. + xiii. $49.50.

State of the World 1988: A Worldwatch Institute Report on Progress Toward a Sustainable Society edited by Linda Starke. 1988. W. W. Norton, New York, NY 10110. 237 pp. + xvii. $9.95.

World Resources 1987: A Report by The International Institute for Environment and Development and The World Resources Institute. 1987. Basic Books, New York, NY 369 pp. + xiii. $16.95.

Field Guides

Fishes of the Pacific Coast: Alaska to Peru, Including the Gulf of California and the Galápagos Islands by Gar Goodson. 1988. Stanford University Press, Stanford, CA 94305. 267 pp. + viii. $7.95.

Stars and Planets, Second Edition by Donald H. Menzel and Jay M. Pasachoff. 1987. The Peterson Field Guide Series, No. 15, Houghton Mifflin Company, Boston, MA 02108. 473 pp. + x. $12.95.

General Reading

Alaska's Seward Peninsula edited by Penny Rennick. 1987. The Alaska Geographic Society, Anchorage, AK 99509. 109 pp. $14.95.

The Flood Myth edited by Alan Dundes. 1988. University of California Press, Berkeley, CA 94720. 452 pp. + vi. $15.95, paper.

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Nautical Quarterly: Number 41, Spring 1988. Nautical Quarterly Co., Essex, CT 06426. 120 pp. $16.00.

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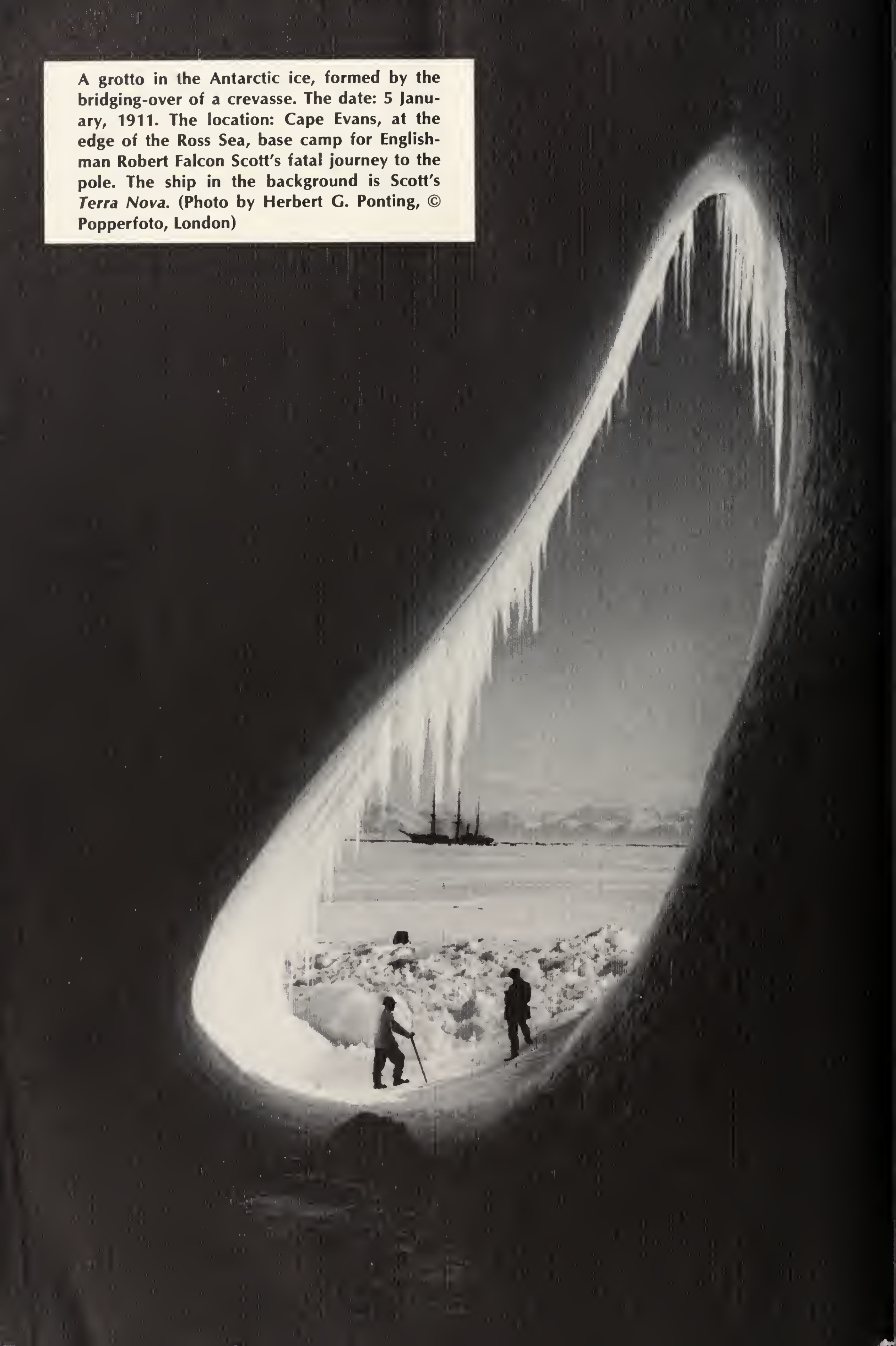

A grotto in the Antarctic ice, formed by the bridging-over of a crevasse. The date: 5 January, 1911. The location: Cape Evans, at the edge of the Ross Sea, base camp for Englishman Robert Falcon Scott's fatal journey to the pole. The ship in the background is Scott's *Terra Nova*. (Photo by Herbert G. Ponting, © Popperfoto, London)